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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

INVESTIGATION TO SELECT SUITABLE WETTING AGENTS AS SULPHIDE ORE DUST SUPPRESSANTS AND TO STUDY THEIR INFLUENCE ON THE FLOTATION PROCESS

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by

M.A. Critovici* and P. Lachapelle**

ABSTRACT

The possibility of using the surfactants as wetting assisting agents for the suppression of sulphide ore dust has been investigated in laboratory. Eighteen surfactants, obtained from the industry, were examined to determine their characteristics (surface tension, solubility, foaming, etc) and to investigate their ability to improve the wetting of the sulphide ore dust. The wetting power was evaluated based on a laboratory procedure measuring the sinkage rate of the dust spread on the surface of the surfactants solution.

Eight surfactants were selected as the most suitable wetting agents for sulphide ore dust.

Investigations were then carried out to determine the effect of the dust-suppression-agents on the flotation process. Two ore samples were used for this testwork: Opemiska copper ore and Brunswick lead-copper-zinc ore. The results of these tests indicated that the flotation selectivity, particularly in the case of poly-sulphides ore (Brunswick) was adversely affected by the presence of the wetting agents.

Continuation of the research program is proposed to study the possibility of eliminating the detrimental effect of the surfactants in the sulphide ore flotation.

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ÉTUDE COMPARATIVE D'AGENTS MOUILLANTS DESTINÉS À COMBATTRE LA POUSSIÈRE DE MINERAIS SULFURÉS ET ESSAIS POUR ÉTABLIR LEUR INFLUENCE SUR LA FLOTTATION DE CES MINERAIS

par

M.A. Cristovici* et P. Lachapelle**

RÉSUMÉ

On a étudié en laboratoire la possibilité d'utiliser des agents tensio-actifs à titre d'agents mouillants pour faciliter la suppression de la poussière de minerais sulfurés. On a examiné dix-huit agents tensio-actifs, obtenus de l'industrie, afin de déterminer leurs caractéristiques (tension superficielle, solubilité, pouvoir moussant, etc.) et d'examiner leur capacité à mouiller la poussière des minerais sulfurés. Pour étudier le pouvoir mouillant, on s'est basé sur un procédé de laboratoire mesurant la vitesse d'immersion de la poussière dispersée à la surface de la solution d'agents tensio-actifs. On a choisi les huit agents tensio-actifs les plus appropriés au mouillage de la poussière du minerais sulfurés.

On a ensuite fait des études pour déterminer les effets des agents de suppression de la poussière sur la flottation. On a utilisé deux échantillons de minerai pour ces essais: un minerai de cuivre (Opemiska) et un minerai de plomb-cuivre-zinc (Brunswick). Les résultats de ces essais ont démontré que la sélectivité de flottation, particulièrement dans le cas du minerai sulfuré complexe (Brunswick) était influencée défavorablement par la présence des agents mouillants.

On propose de poursuivre ce programme de recherche afin d'étudier la possibilité d'éliminer l'effet défavorable des agents tensio-actifs sur la flottation des minerais sulfurés.

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INTRODUCTION

Dust measurements in mines clearly indicated (1,2) that the major mineral dust exposure is due to loading and transport of the ore from the mining areas. Dust clouds at transfer and loading points, for example, may arise from breakage of large lumps as a result of impact after free fall and from re-dispersion of fine material already present in the pile of ore. One approach to the solution of this dust problem is the application of water sprays to reduce dust dispersion. Wetting of broken rock is very effective in preventing fine dust from becoming airborne by binding it to the larger lumps. Experiments have shown that most common rocks are readily wetted by water. However, the dust originating from sulphide minerals exhibits an inherent hydrophobicity that makes water spreading on the surface of the particles more difficult, creating problems in dust suppression.

The surfacants are known to be able to reduce the surface tension of the water facilitating thus the wetting and the suppression of the sulphide ore dust, but on the other hand the flotation of the sulphide ore is susceptible to interference by surfactants.

Thus a laboratory study was initiated to examine the effects of surfactants both on the wetting of sulphide ore dust and on the flotation process prior to carrying out field trials on the efficiency of dust suppression. This study forms part of the CANMET subactivity program dealing with Health and Safety in mining.

The laboratory dust wetting test is likely to grade wetting agents in approximately the same ranking order as would field tests, but is unlikely to be useful in determining approximate concentrations for field use, which experience has indicated are probably substantially greater.

The flotation cell used for the testwork was a laboratory machine, which gave a reasonable approximation to the performance of the process carried out in the industrial size equipment.

This report covers the results of the laboratory testwork dealing with sulphide ore dust suppression by wetting agents and flotation of sulphide ores in the presence of surfactants, used as dust suppressors.

OUTLINE OF INVESTIGATION

Investigations were carried out to study the possibility of suppressing the sulphide ore dust by wetting agents and to determine the effect of these agents on the flotation process.

Samples of ore from two mining operations: Opemiska and Brunswick Mine were used for this testwork.

The wetting agents were supplied by various manufacturers of chemicals in Canada.

OBJECTIVES OF THE INVESTIGATION

The main objectives of the investigation were:

a) selection of suitable dust wetting agents, and

b) study of the influence of the wetting agents on the flotation process.

SELECTION OF SUITABLE DUST WETTING AGENTS

The testwork was carried out on dust obtained from the following ore samples:

- Opemiska waste rock, containing practically no sulphide minerals (0.32% S);
- Opemiska copper ore with low sulphides content, mainly as chalcopyrite (5.27% S); and
- Brunswick complex ore with high sulphides content, mainly as galena, sphalerite and pyrite (15.88% S).

The dust was obtained by crushing the samples to -12 mm in successive steps and then separating, by screening, the dust product as the -37 microns fraction.

The wetting agents were supplied by various manufacturers of chemicals replying to our inquiry for this specific application.

Several wetting agents were selected based on the results of the following examinations:

a) ability to wet the sulphide ore, evaluated on the basis of the sinkage rate expressed in mg/s and determined as the required time, in seconds, for the wetting and complete immersion of 1000 mg dust spread at the surface of the water-surfactants solution;

b) solubility in cold water;

c) maximum foaming expressed as the ratio between the volume of froth produced by shaking a surfactant solution in a test tube and leaving it to rest for a minute and the initial volume of the solution; and
d) safety in terms of toxicity and fire hazard.

Based on these criteria a number of wetting agents were selected. Table 1 summarizes the results of the examinations.

Sinkage rate of the dust in the beaker test was the most important criterion in selecting the wetting agents. In water, without surfactants the Opemiska waste rock dust required 16 minutes to achieve complete immersion (sinkage rate: 1.04 mg/s), while for the sulphide ore the required settling time was 20 minutes (sinkage rate: 0.83 mg/s) confirming the well-known fact that the sulphides are less wettable than the silicates. The surface tension of the water (76.2 dyne/cm) was reduced, in the presence of the selected surfactants to 30-35 dyne/cm, causing an almost instantaneous immersion of the sulphide ore dust (sinkage rate: 1000 mg/s) in the solution. One reagent with only 67 mg/s sinkage rate was also included in the selected agents because it was by far superior to those that were eliminated.

INFLUENCE OF THE WETTING AGENTS ON THE FLOTATION PROCESS

This investigation was carried out to reveal the possible detrimental effect of the wetting agents, supposedly added in the mining operation as dust suppressants, on the flotation process.

This testwork was performed on laboratory stage and simply consisted in adding the wetting agents to the ore prior to the grinding and then, carrying out the flotation under the conditions presently used in the respective plant, namely Opemiska and Brunswick Mill. The surfactants were added as 2% solution in water, in the amount varying from 2.5 - 50.00 L solution/t of ore.

Table 2 summarizes the results of the flotation testwork in the presence of the selected wetting agents versus no surfactants additon.

As can be seen from the data of this table the flotation results were adversely affected by the presence of the wetting agents, in a great measure for Brunswick ore and to a much lesser extent for Opemiska ore. In the flotation of the Opemiska ore (single mineral flotation) the grade of the concentrate dropped somewhat, mainly because the excess froth due to the presence of the wetting agents carried along some extra weight. For most of the surfactants the copper recovery was not affected.

Table 1 - Selected dust-wetting agents

Wetting agent	Manufacturer	Type, chemical name	Agent lowest conc for fast sinkage of dust %	Surf. tens. of sol'n dyne/cm	Sinkage rate mg/s		Solubility in cold water	Ratio: (vol) foam / sol'n	Safety	Price $/kg
					Opemiska	Brunswick				
Antarox CO-610	G.A.F.	Nonylphenoxypoly ethanol-Nonionic	0.1	33.43	1000	1000	very good	0.35	normal precautions	3.10
Sterling NP10	Canada Packers	Ethoxylated Nonyl Phenol-Nonionic	0.1	34.40	1000	1000	good	1.60	normal precautions	2.07
Aerosol OT-S	Cyanamid	Sodium dioctylsulfo-succinamate-Anionic	0.1	30.60	1000	1000	very good	1.00	normal precautions	3.00
Aerosol O.P.G.	Cyanamid	Sodium dioctylsulfo-succinamate-Anionic	0.1	29.60	1000	1000	very good	1.90	normal precautions	1.90
C.E.S.-372	Armak	Polyethylene glycol ester-Nonionic	2.0	36.85	67	67	very good	0.25	normal precautions	1.78
E2943-145-1	Dow Corning	Not known silicone based	1.0	30.00	1000	1000	very good	0.75	not assessed	not available
E2943-145-3	Dow Corning	Not known silicone based	0.5	25.80	1000	1000	very good	2.75	not assessed	not available
E2943-145-4	Dow Corning	Not known silicone based	2.0	32.60	1000	1000	very good	2.70	not assessed	not available

In the case of Brunswick ore (selective, multi-mineral flotation) the wetting agents interfered with the process before any collectors or frother were added, by creating an excessive, uncontrollable froth during the aeration period, a stage presently used in the Brunswick mill, prior to the lead-copper flotation. Following that it was decided to eliminate the aeration, to be able to control the process and compare the effect of the wetting agents among themselves. Even so, under no aeration condition, the selectivity in the lead-copper flotation was severely affected, by having a large amount of zinc carried in the froth, reducing thus the grade of this concentrate, below 20% Pb, versus over 40% Pb when no wetting agents were used. (For simplicity the copper results were not given in Table 2). Also, the zinc loss in the lead concentrate was extremely high (14 - 36%) as compared with 8.5% when no surfactant was employed.

In the zinc flotation, the grade of the concentrate was not affected too much by the presence of the wetting agents, however, the zinc recovery dropped.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the up-to-date results of this study, dealing with the wetting agents as sulphide dust suppressants, the following conclusions can be drawn:

A) Laboratory investigations, based on the sinkage rate of the dust placed in a beaker containing wetting agents, have indicated that the surfactants added to the water had drastically improved the spreading of the liquid on the surface of the dust, suggesting that under wetting agents spraying the suppression of the sulphides dust can be achieved.

B) The laboratory experiments carried out to reveal any possible detrimental effect of the wetting agents in the flotation process concluded:
   a) In the case of a single mineral flotation the presence of the surfactants deteriorated the concentrate grade to a certain extent but in most of the cases did not decrease the metal recovery.
   b) For a complex, Pb-Cu-Zn ore, where a differential flotation had to be applied, the addition of the surfactants had adversely affected the selectivity in the lead-zinc separation, by having the Pb-Cu concentrate contaminated with a large amount of zinc.

Table 2 - Flotation results with and without surfactans addition

Wetting agent 2% sol'n 10 L sol'n/t of ore	Opemiska			Brunswick										
	Copper conc			Lead conc					Zinc conc					
		Assay %	% Recov		Assay %		% Recov			Assay %		% Recov	
	% wt	Cu	Cu	% wt	Pb	Zn	Pb	Zn	% wt	Pb	Zn	Pb	Zn
None	19.3	24.77	94.2	9.9	43.61	12.54	76.4	8.4	20.1	1.46	54.72	5.2	74.8
Antarox CO-610	19.7	22.69	94.9	38.7	16.10	13.35	87.7	36.1	11.1	1.19	57.93	1.9	45.0
Sterling NP10	20.0	21.74	95.5	38.6	13.21	13.66	84.8	36.2	12.9	1.41	54.33	3.0	48.1
Aerosol OT-S	21.4	15.98	76.9	26.9	18.50	15.40	83.1	27.5	21.6	1.15	42.26	4.1	60.8
Aerosol GPG	20.8	18.27	74.7	28.8	16.70	14.00	82.6	26.8	17.8	1.16	45.10	3.5	53.4
Armak CES-372	19.7	20.34	92.6	39.6	15.71	12.41	89.1	33.9	13.3	1.03	51.86	2.0	48.3
Dow E2943-145-1	20.8	21.31	96.1	28.6	17.94	10.03	77.4	19.7	15.7	1.19	51.44	2.8	55.5
Dow E2943-145-3	22.9	20.15	98.0	34.7	14.53	15.35	89.2	35.5	14.3	0.79	48.83	2.0	46.1
Dow E2943-145-4	19.9	22.90	96.6	25.8	18.06	10.60	73.5	18.7	15.1	0.91	54.81	2.2	56.6

The detrimental effect of the surfactants for the flotation process was attributed to their frothing and possibly some collecting properties. The excess froth have caused the undesirable constituents to float along with the useful mineral, affecting thus the grade of the concentrate. Meanwhile possible collecting properties of the wetting agents might have interfered with the action of the depressants, since the surfactants were added prior to the flotation reagents, destroying thus the selectivity in the differential flotation.

Although the flotation results in the presence of the wetting agents were unacceptable, the finding of a series of wetting agents that acted as good sulphides dust suppressants, warrants the continuation of the investigation to determine the conditions under which the flotation process will not be adversely affected by the surfactants.

The following recommendations are made regarding the lines of investigation that should be further pursued to find means that will eliminate the detrimental effect of the dust suppressant-wetting agents in the sulphides flotation:

1. Request the research group of the manufacturers that supplied the best wetting agents to study possible changes of the physico-chemical characteristics of the surfactants to reduce their frothing-collecting properties;
2. Investigate possible adjustment of the flotation reagents regime (amount and points of addition) to accomodate for the extra frothing-collecting action due to the wetting agents;
3. Study the possibility of annhiliating the effect of the wetting agents in the pulp by trying to adsorb the excess reagents on activated carbon or similar materials;
4. Verify the effect of the wetting agents in the selective flotation of other poly-mineral ores less difficult to process than that of the Brunswick Mines (for example: ore from Noranda Mines, Texasgulf Canada, Cominco Ltd., etc).

DETAILED DESCRIPTION OF THE TESTWORK

The testwork carried out to select suitable wetting agents as sulphide dust suppressants and to investigate the influence of the surfactants

on the flotation process was conducted according to the following program:

- preparing the ore samples and producing the required dust for the experiments;
- contacting chemical suppliers and obtaining samples of surfactants considered appropriate for this application;
- selecting the most suitable wetting agents for sulphide ore dust, and
- investigating the effect of the selected surfactants on the flotation of two types of ore sample.

Detailed description of this testwork follows.

ORE SAMPLES: PREPARATION AND PHYSICO-CHEMICAL CHARACTERISTICS

Three ore samples were used for the testwork:

- waste rock sample from Opemiska mine;
- copper sulphide ore sample from Opemiska mine, and
- lead-copper-zinc sulphide ore sample from Brunswick mine.

The Opemiska waste rock sample was practically sulphides free (S:0.32%) and it was used as a reference material for testing the behaviour of the dust generated by low and high sulphide ores.

Opemiska copper ore sample had a low sulphides content while the sulphides concentration in the Brunswick sample was in the medium-high range. In the flotation of Opemiska copper ore one mineral (chalcopyrite) only is recovered while the flotation process of Brunswick ore deals with the separation of two groups of minerals: galena-chalcopyrite and sphalerite.

The ore samples were prepared for chemical analysis and testwork by crushing them stagewise to 12 mm and 2 mm.

From the -2 mm crushed ore, head samples were riffled out, pulverized and submitted for chemical assay.

From the 12 mm material charges of 10 kg were removed and screened on 37 microns sieve. The -37 microns fraction represented the dust product which was used in the testwork.

Finally, charges of 1 kg, -2 mm ore were riffled from Opemiska copper ore and Brunswick complex ore for the flotation experiments.

The head assays of the samples are given in Table 3.

Table 3 - Samples head assay

Sample	% Assay					
	Pb	Cu	Zn	S	Fe	SiO_2
Opemiska waste	0.01	0.11	0.01	0.32	11.22	52.01
Opemiska copper ore	0.02	4.39	0.08	5.27	15.98	41.83
Brunswick ore	5.78	0.18	14.76	15.88	17.08	31.67

Size distribution of the ore samples crushed at 12 mm and -2 mm as well as the subsieve structure of the -37 microns fraction (dust product) are shown in Table 4, 5 and 6 respectively.

Table 4 - Size distribution of -12 mm ores

Size	Opemiska waste			Opemiska copper			Brunswick		
	% Retained		% Pass	% Retained		% Pass	% Retained		% Pass
mm	Ind*	Cum**	Cum	Ind	Cum	Cum	Ind	Cum	Cum
6.4	48.6	48.6	51.4	62.3	62.3	37.7	56.6	56.6	43.4
3.4	16.7	65.3	34.7	13.7	76.0	24.0	15.4	72.0	28.0
1.7	13.0	78.3	21.7	8.5	84.5	15.5	11.1	83.1	16.9
-1.7	21.7	100.0	-	15.5	100.0	-	16.9	100.0	-
Total	100.0	-	-	100.0	-	-	100.0	-	-

*Individual

**Cumulate

Table 5 - Size distribution of -2 mm ores

Size	Opemiska waste			Opemiska copper			Brunswick		
	% Retained		% Pass	% Retained		% Pass	% Retained		% Pass
Microns	Ind	Cum	Cum	Ind	Cum	Cum	Ind	Cum	Cum
841	34.7	34.7	65.3	28.4	28.4	71.6	32.2	32.2	67.8
420	26.6	61.3	38.7	20.8	49.2	50.8	20.7	52.9	47.1
297	9.2	70.5	29.5	8.4	57.6	42.4	7.2	60.1	39.9
210	7.8	78.3	21.7	5.9	63.5	36.5	5.0	65.1	34.9
149	5.5	83.8	16.2	5.5	69.0	31.0	5.0	70.1	29.9
105	5.8	89.6	10.4	5.1	74.1	25.9	5.0	75.1	24.9
74	3.4	93.0	7.0	4.8	78.9	21.1	5.5	80.6	19.4
53	2.6	95.6	4.4	1.8	80.7	19.3	2.7	83.3	16.7
37	2.7	98.3	1.7	3.6	84.3	15.7	2.5	85.8	14.2
-37	1.7	100.0	-	15.7	100.0	-	14.2	100.0	-
Total	100.0	-	-	100.0	-	-	100.0	-	-

Table 6 - Subsieve structure of the -37 microns fraction (dust)

	Opemiska waste			Opemiska copper			Brunswick		
Size	% Retained		% Pass	% Retained		% Pass	% Retained		% Pass
Microns	Ind	Cum	Cum	Ind	Cum	Cum	Ind	Cum	Cum
+32	6.0	6.0	94.0	8.5	8.5	91.5	22.7	22.7	77.3
23	20.3	26.3	73.7	19.6	28.1	71.9	26.1	48.8	51.2
17	22.9	49.2	50.8	20.9	49.0	51.0	18.8	67.6	32.4
12	23.2	72.4	27.6	20.6	69.6	30.4	15.0	82.6	17.4
9	10.7	83.1	16.9	10.2	79.8	20.2	4.8	87.4	12.6
- 9	16.9	100.0	-	20.2	100.0	-	12.6	100.0	-
Total	100.0	-	-	100.0	-	-	100.0	-	-

DESCRIPTION OF WETTING AGENTS USED IN THE TESTWORK

The wetting agents used in the testwork are listed below along with the suppliers name.

No.	Reagent	Supplier
1	Coherex	C.I.L. for WITCO
2	Antarox CO-610	G.A.F.
3	Tergitol 08	Bate chemical
4	Sterling NP10	Canada Packers
5	Sterling AOS	Canada Packers
6	Sterling Snow White 750	Canada Packers
7	Aerosol OT-100	Cyanamid
8	Aerosol OT-S	Cyanamid
9	Aerosol GPG	Cyanamid
10	Ethomeen C/15	Armak
11	Armak CES 372	Armak
12	Armak CES 265	Armak
13	Dow Q4-3667 Fluid	Dow Corning
14	Dow HV-490 Emulsion	Dow Corning
15	Dow E-2943-145-1	Dow Corning
16	Dow E-2943-145-2	Dow Corning
17	Dow E-2943-145-3	Dow Corning
18	Dow E-2943-145-4	Dow Corning

Following is a description of the physico-chemical characteristics of these surfactants, their present application as well as some safety and market considerations.

1. Coherex

Coherex dust retardant is a dust control agent developed by the Golden Bear Division of Witco Chemical Corporation.

It is a stable, concentrated, non-volatile emulsion consisting of approximately 60% petroleum resins and 40% wetting solution. The resins are the film-forming, dust-binding portion. The wetting solution keeps the petroleum resins dispersed in finely divided particles and makes Coherex readily miscible with water, even sea water.

Presently, Coherex is used as a commercial dust retardant for roads and utility yards, construction areas, sand dunes, etc.

From a safety and handling point of view it is neither flammable nor combustible having a flash point over 204°C and it is practically non-toxic.

The cost of product is $0.90/kg in truckload quantities.

2. Antarox CO-610

Antarox is a nonylphenoxypoly (ethyleneoxy) ethanol from the family of non ionic surfactants. The trade name of the product tested in this program is Igepal CO-610. The active content of the surfactant is essentially 100%.

At 25°C it is a free flowing slightly viscous liquid. It is completely soluble in water, has a boiling point above 260°C and a flash point at 218 - 229°C.

The surface tension of the product, solution 0.01%, at 25°C is 30 dynes/cm.

Antarox CO-610 is used in all phases of textile processing as surfactant, in metal processing involving mineral acids and corrosion inhibitors as wetting agent, for household and industrial cleaners as surfactants, etc.

The use of this reagent does not require special precaution in handling or storage.

The cost of the product is $3.10/kg in 215 kg shipment.

3. Tergitol 08

Tergitol 08, also known as Niaproof anionic surfactant 08, is available in an aqueous solution containing 40% by weight of sodium 2-ethylhexyl sulfate.

Its appearance is essentially a colourless liquid, chemically stable and miscible in water at 20°C. The surface tension of the reagent 0.1% aqueous solution is 63 dynes per cm.

The product is used in textile processing as surfactant, in metal processing, household and industrial cleaning, etc.

Tergitol 08 is regarded as a material of moderate oral and skin penetration toxicity. It has no flash point and it is comparatively safe to store and handle, however, contact with eyes and skin should be avoided.

The cost of the product is $2.65/kg in shipment of 10 drums or more.

4-6. Sterling surfactants

Sterling NP10 is a nonyl phenol polyglycol ether condensate, a surfactant of nonionic type. Active substance is 100% and the physical appearance is clear, viscous liquid. It is stable in strong acids or alkaline solutions. The product is used as a wetting and penetrating agent for textile processing, as a base in the manufacture of industrial and household cleaners, etc. The cost of the sufectant is $2.07/kg in shipment of 217 kg.

Sterling AOS is an anionic surfactant. Its chemical composition is: 39% active sodium alpha olefin sulphonate. It has high foaming and detergency properties in both hard or soft water. It is used as a replacement for the alkylbenzene sulphonate to improve mildness to the skin, in liquid detergents.

Sterling Snow White 750 is a cationic fabric softener product containing 75% active substance. It forms stable emulsions with water and it is used as a concentrate to formulate household or commercial fabric softeners.

Sterling NP10 requires normal precautions in handling and storage. Contact with skin and eyes should be avoided.

7-9. Aerosol surfactants

Aerosol OT surfactant is a sodium dioctyl sulphosuccinate of anionic type and is available in 5 grades among which the following three were used in the testwork:

a) OT-100, waxy solid, active substance 100%, decomposes at 235°C and has a solubility of 15 g/L in water at 25°C. Surface tension in water at 0.1% concentration is 28.7 dynes/cm.
b) OT-S, a 70% solution in light petroleum distillate is dispersible in water and has a boiling point at 188 - 208°C.
c) GPG, a clear, slightly vicous liquid is a mixture of sodium dioctyl sulfosuccinate, ethanol and water. It contains 67 - 73% active substance and has a surface tension of 28.7 dynes/cm for 0.1% solution in water.

The Aerosol surfactants are used as wetting agents and emulsifiers in various industrial applications. The use of Aerosol wetting agents has shown some beneficial results in ore dressing. The addition of small amounts of Aerosol in cyanidation tanks has resulted in higher extraction, apparently due to the disintegration or penetration of slimes aggregates. In flotation

Aerosol agents are finding use as a gangue dispersant in the treatment of oxide and non-metallic minerals.

Except for eye exposures, Aerosol surfactants exhibit a low order of toxicity. Persons handling these reagents should avoid eye contact and preferably wear rubber gloves.

Reagent cost for 215 kg shipment is: US $2.45/kg for OT-S and US $1.54/kg for G.P.G.

10-12. Armak surfactants

The surfactants offered by Armak for testwork as dust suppressants were:

a) CES-372, an industrial grade monooleate ester of a polyethylene glycol and a naturally derived fatty acid. Its appearance at 25°C is a dark brown liquid. It has a flash point greater than 255°C and is a non-corrosive, non-hazardous liquid. Though it does not cause primary skin or eye irriation it is still recommended to wear protective gloves and eye goggles when handling this material. This reagent finds wide application as a non ionic emulsifier.

b) CES-265, also called ethofat T/25 is a surfactant with 100% content of polyethylene glycol ester. At ambient temperature it is a brown paste and disperses in water. The flash point is 260°C. It is labelled as non hazardous reagent, however, splash goggles for eye protection and gloves are recommended when handling this surfactant.

c) Ethomeen C/15 is a polyoxyethylene (5) cocoamine with appearance of a clear liquid. Solution of 0.1% surfactant has a surface tension of 33 dynes/cm. It disperses in water and the flash point is 238°C. The ethomeen amines are used in formulating adhesives as defoaming agent in the manufacture of paper, etc. The ethomeen are strong oxidizing agents therefore face shield, splash goggles and neoprene gloves are recommended when handling the reagents.

The cost of the Armak Reagents is:

CES-372	$/kg	1.78
CES-265	"	1.87
Ethomeen C/15	"	4.17

14-18. Dow Corning reagents

The reagents supplied by Dow to be tested as wetting agents were:

a) Q4-3667 Fluid is a silicone polycarbinol. Structurally the reagent is a polydimethylsiloxanes containing alcohol functional groups grafted onto the siloxane chain. It is soluble in water at 1% concentration and has the flash point at 140°C. Among other properties the reagent is expected to improve the water repellency of the organics. The cost of the reagent is estimated at $14.16/kg.

b) HV-490 Emulsion is a silicone release reagent containing dimethyl polysiloxane fluid. It is a thin liquid, soluble in water. Primary use is as release agent for rubber plastics and metals. The cost of the reagent is not known.

c) The reagents identified as E-2943-145 No 1 - 4 are products in the experimental stage. They are silicone glycols type surfactants, soluble in water with surface tension values at 0.01% concentrations in the range of 27 - 33 dyne/cm. The cost of these reagents has not been yet evaluated.

The toxicology of Dow reagents used in this testwork has not been assessed.

TESTWORK FOR SELECTING THE MOST SUITABLE WETTING AGENTS

The reagents received from various manufacturers were subjected to a number of tests to determine their ability to act as dust suppresants for sulphide ore dust.

Selection of the most suitable wetting agents was based on the following measurements and experiments.

Measurements to Determine the Surface Tension of the Surfactants

The surface tension of the surfactants, at various concentrations in water, was determined using a Fisher Tensiometer with platinum-iridium ring of 6 cm circumference.

The results of these determinations are shown in Table 7 and Fig. 1 and 2.

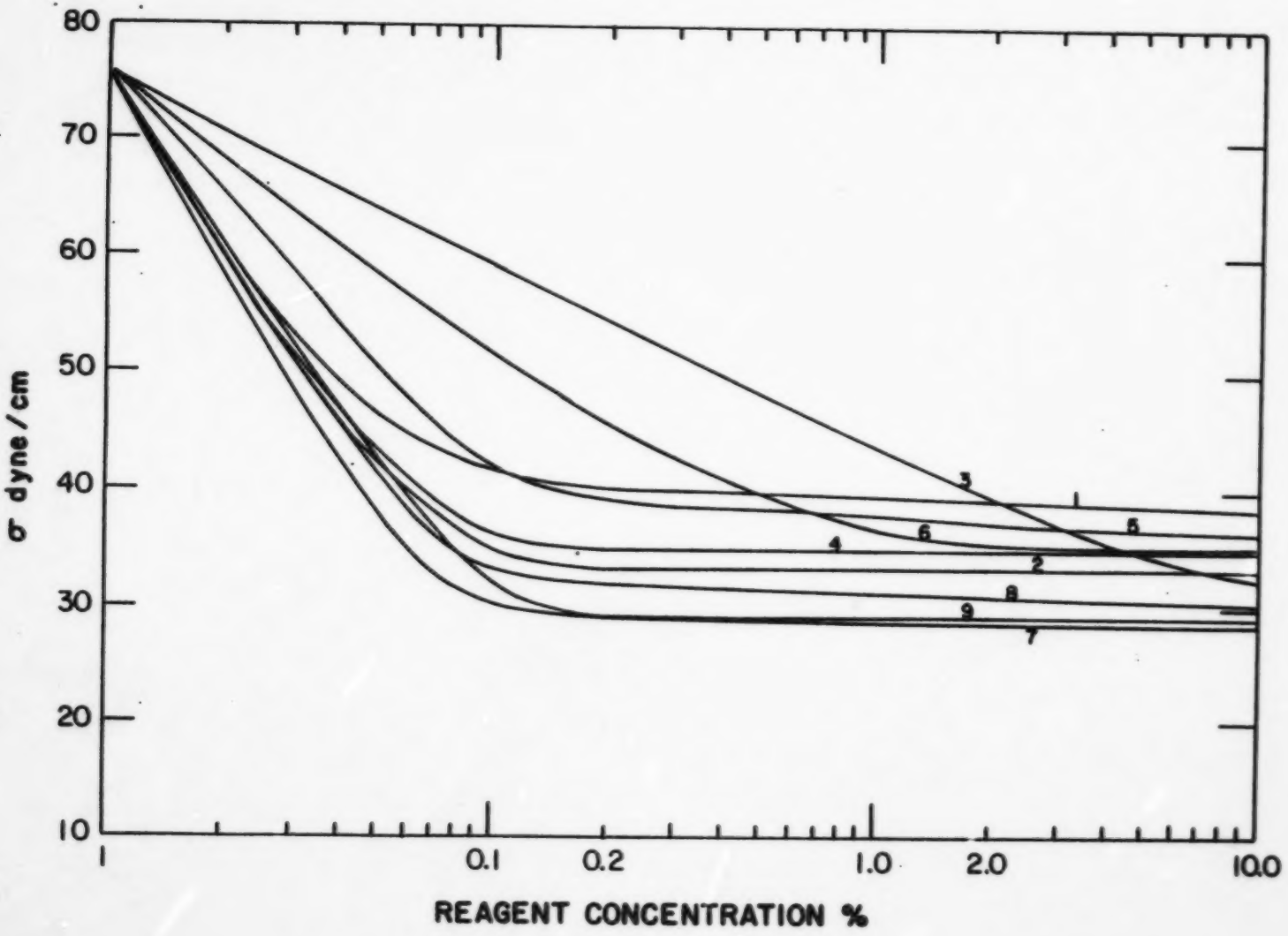
All the reagents added to the water in concentration varying from 0.1 - 10% by weight, drastically reduced the surface tenison of the water.

Among them, Aerosol OT-100 and GPG as well as Dow E-2943-145 1 and 3 were able to lower the surface tension of the water below 30 dynes/cm.

Table 7 - Surface tension of the reagents at various concentrations

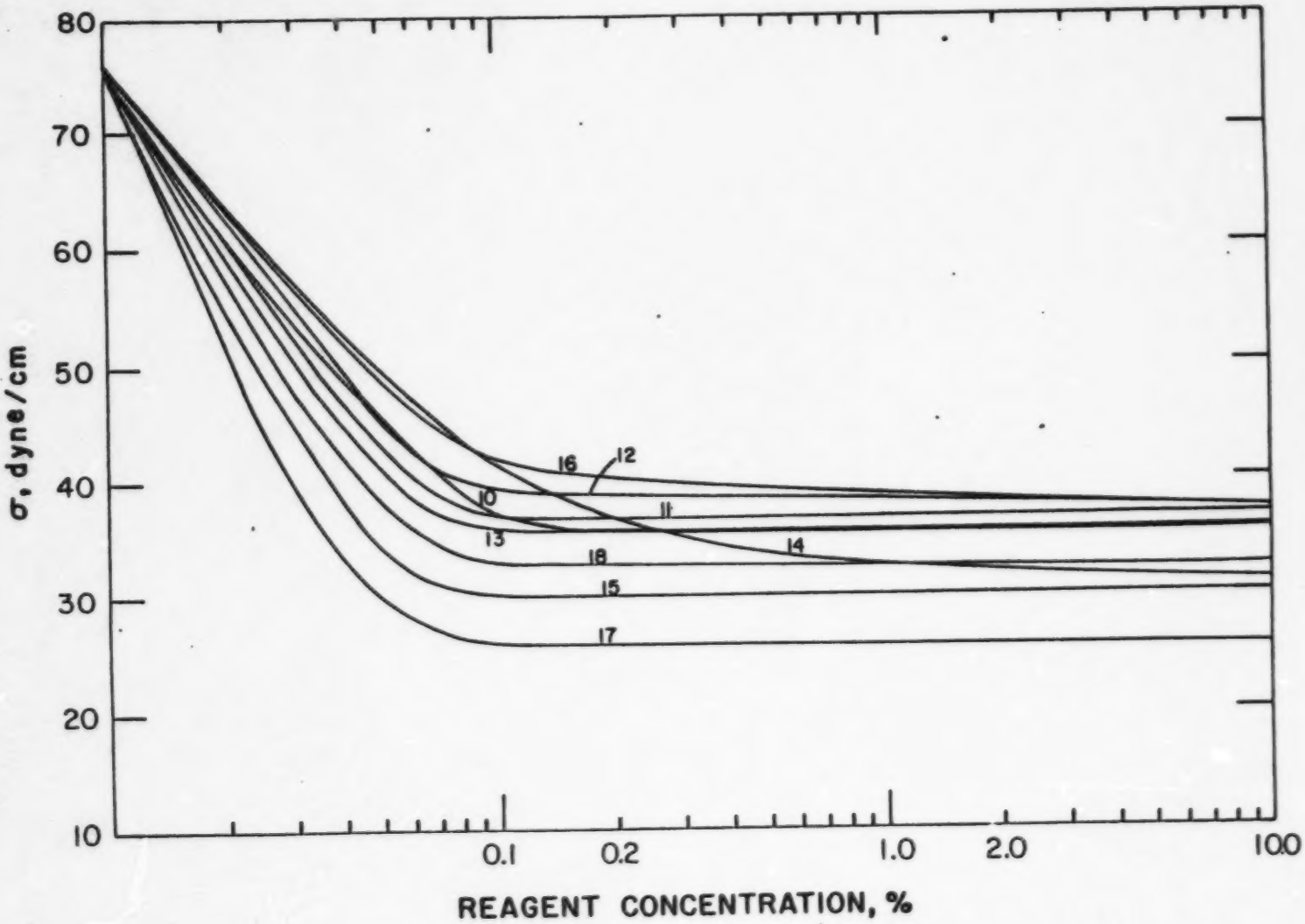
		Surface tension, dynes/cm			
No.	Surfactant	Conc 0.1%	Conc 2.0%	Conc 5.0%	Conc 10%
1	Coherex	41.7	39.5	39.0	37.4
2	Antarox CO-610	33.4	33.9	33.3	33.6
3	Tergitol 08	59.1	44.8	34.5	32.2
4	Sterling NP10	34.4	34.9	35.0	35.0
5	Sterling AOS	32.1	37.1	36.8	36.2
6	Sterling Snow White 750	51.7	35.5	36.5	
7	Aerosol OT-100	28.4	28.7	29.4	
8	Aerosol OT-S	30.6	30.7	30.7	30.5
9	Aerosol G.P.G.	29.6	29.2	29.2	
10	Ethomeen C/15	35.2	35.8	35.2	35.8
11	Armak CES 372	36.9	36.9	37.4	
12	Armak CES 265	37.3	38.0	37.9	37.0
13	Dow Q4-3667 Fluid	37.1	35.4	35.5	33.1
14	Dow HV-490 Emulsion	41.1	28.5	31.3	32.1
15	Dow E-2943-145-1	29.1	28.6	30.3	29.8
16	Dow E-2943-145-2	34.8	36.8	37.9	37.5
17	Dow E-2943-245-3	26.0	25.0	25.4	25.6
18	Dow E-2943-145-4	32.3	32.6	33.5	32.2

Fig. 1 - Surface tension of the surfactants solution as function of the reagent concentration (Reagents 1-9)



1. Coherex
2. Antarox CO-610
3. Tergitol 08
4. Sterling NP10
5. Sterling AOS
6. Sterling Snow White
7. Aerosol OT-100
8. Aerosol OT-S
9. Aerosol GPG

Fig. 2 - Surface tension of the surfactants solution as function of the reagent concentration (Reagents 10-18)



10. Ethomeen C/15
11. Armak CES 372
12. Armak CES 265
13. Dow Q4-3667
14. Dow HV-490
15. Dow E-2943-145-1
16. Dow E-2943-145-2
17. Dow E-2943-145-3
18. Dow E-2943-145-4

Tests to Evaluate the Wetting Ability of the Surfactants

The most important criterion in selecting suitable surfactants was based on their wetting properties for this particular material (sulphide ore dust), which presumably will reflect their ability to act as dust suppressants in industrial application.

The laboratory method used to determine the effect of various surfactants on the wettability of sulphide ore dust from Opemiska and Brunswick ores, consisted in allowing a measured quantity of sulphide ore dust, spread at the surface of the reagent solution contained in a 500 mL beaker, to get wet and descend to the bottom of the vessel (Fig. 3a,b,c). The efficiency of this wetting action was evaluated on the basis of the ore dust sinkage rate, expressed in mg/s and determined as the required time in sonds for wetting and sinking a quantity of 100 mg sulphide ore dust spread on the surface of the reagent solution.

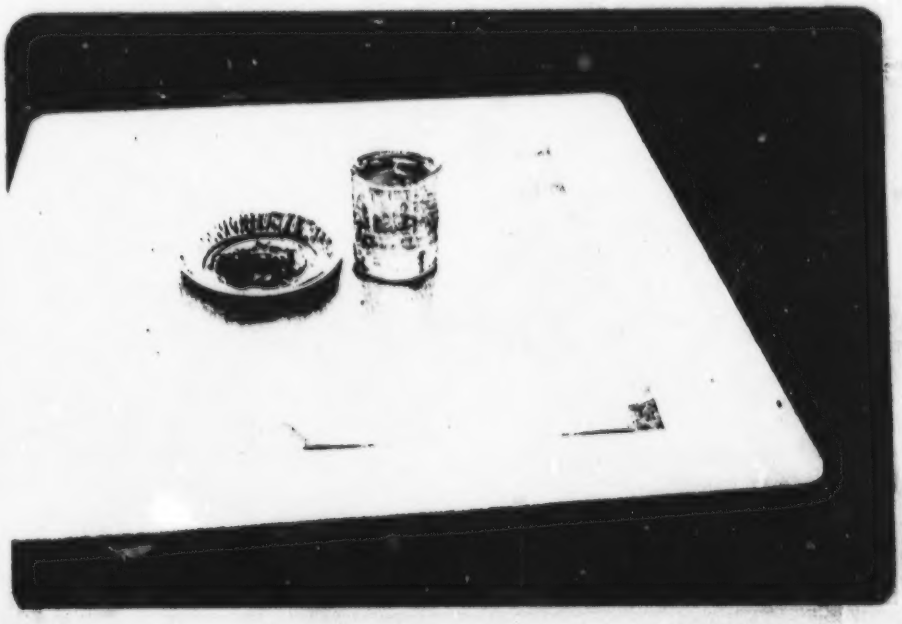


Fig. 3 - Laboratory procedure used to evaluate the dust sinkage rate. (a) Dust sample on a plate; dust sample spread on the surface of the sufactant solution.

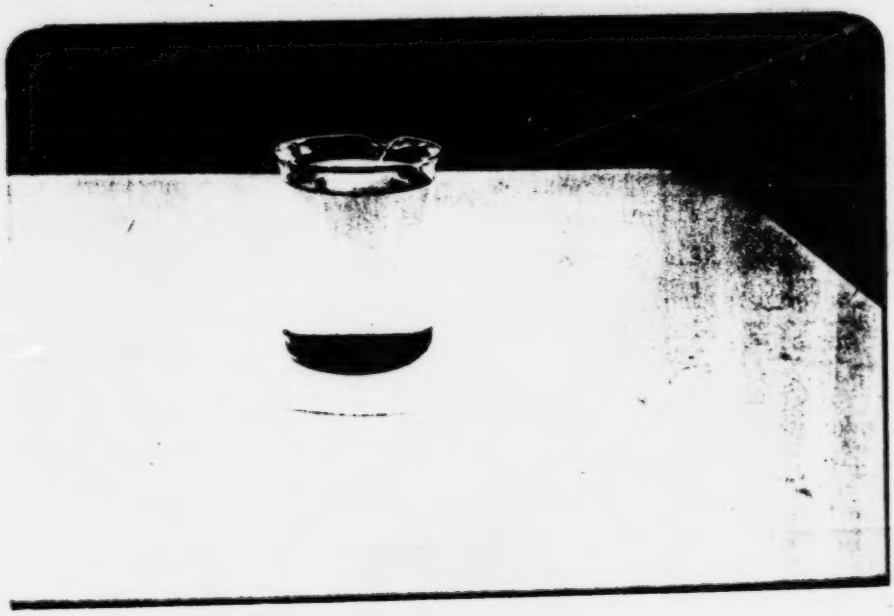


Fig. 3(b)

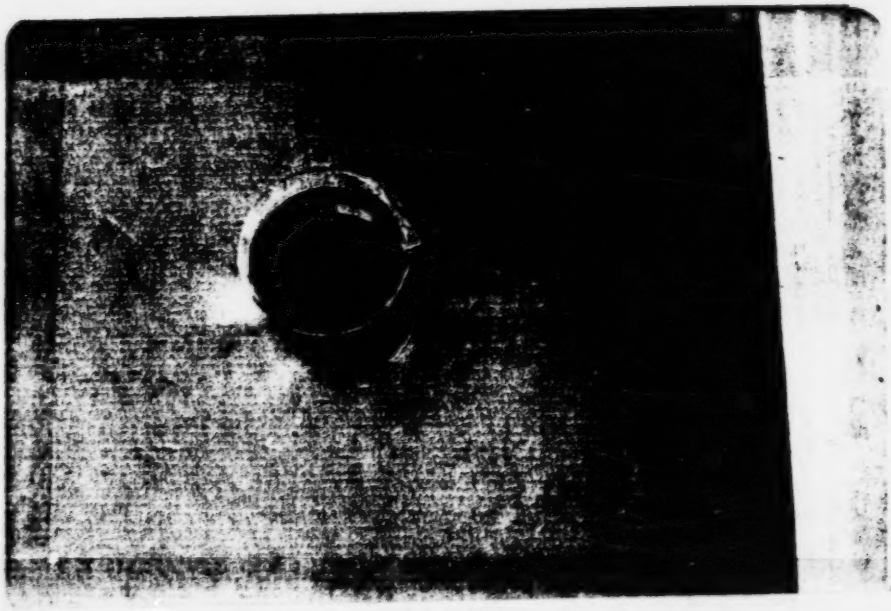


Fig. 3(c)

Laboratory procedure used to evaluate the dust sirkage rate. Dust sample descended at the bottom of the vessel after complete wetting by the surfactant solution. Side view (b); top view (c).

This sinkage rate of the Opemiska and Brunswick sulphide ore dust was also determined for water, without any surfactant addition, as a reference condition.

The results of the sinkage test, in water with no surfactants addition are given in Table 8.

Table 8 - Sinkage rate of the ore dust in water

	Sinkage	
		Rate
Ore dust	Sec	mg/sec
Opemiska waste rock	960	1.04
Opemiska sulphide ore	1200	0.83
Brunswick sulphide ore	900	1.11

Comparing the sinkage of Opemiska dust, waste versus sulphide ore, it showed, as expected, that the sulphide dust was less wettable than the waste rock dust, requiring a longer time to get complete wetting and immersion in water. Therefore the sinkage rate for sulphide dust was inferior to that of the waste rock dust.

As regards to the Brunswick ore it can only be mentioned that the dust exhibited low sinkage rate in water, but no comparison could be made with Opemiska waste or sulphide dust because the mineral constituents and the specific gravity of the two ores were different.

The results of the sinkage tests using sulphide dust from Opemiska and Brunswick ore at various surfactants concentrations are shown in Table 9 and Fig. 4 and 5.

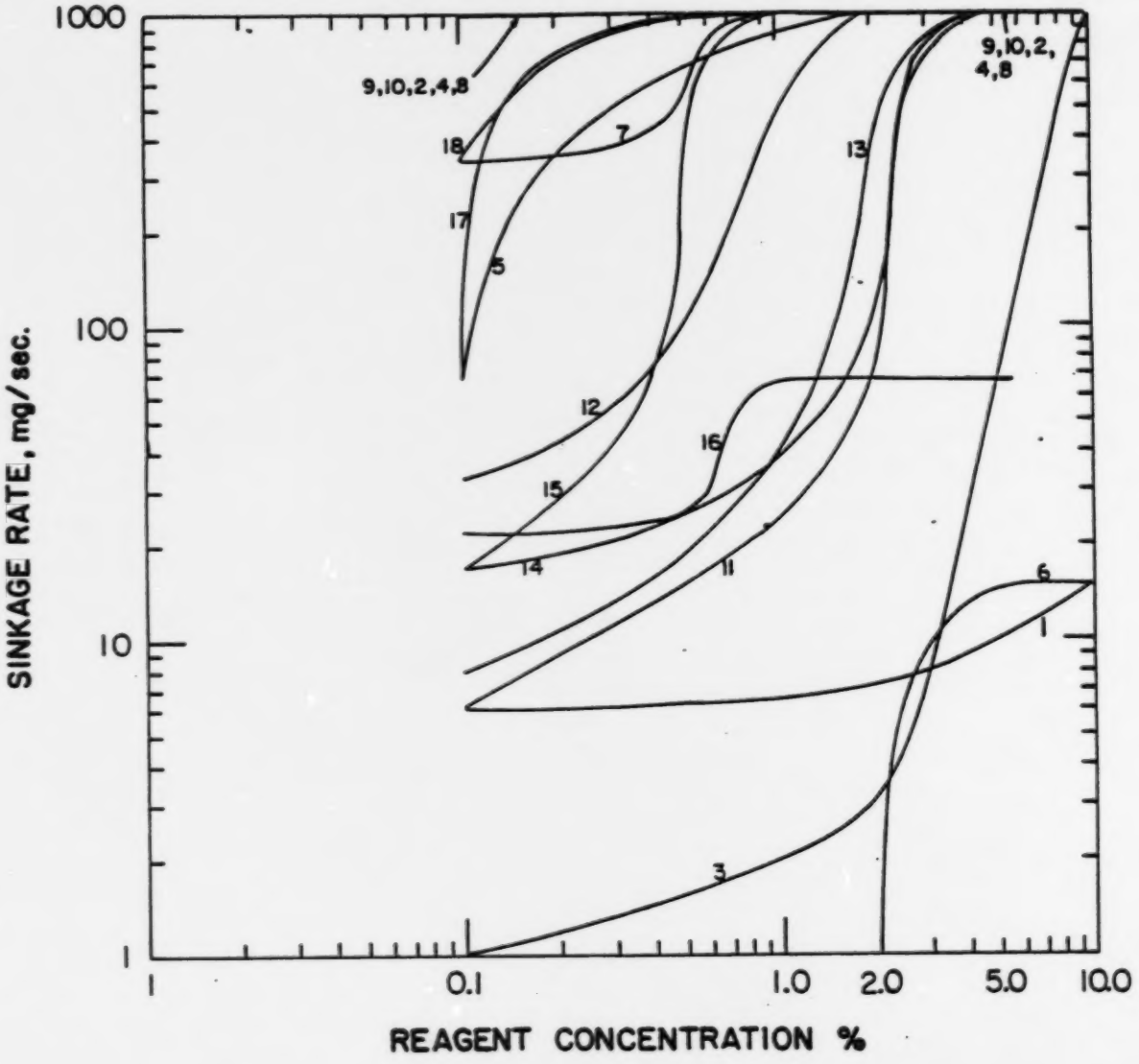
Many of the reagents tested by this method produced a drastic decrease of the surface tension of the water allowing it to spread fast on the surface of the dust particles, wetting them and causing their rapid sinkage. For some of the surfactants their wetting action was so efficient that the dust particles descended almost instantaneously (less than 1 s) to the bottom of the beaker. The sinkage rate for this fast wetting agents reached 1000 mg/s.

The selection of the surfactants by the wetting ability test was based on the condition to achieve a sinkage rate of minimum 60 mg/s, for both Opemiska and Brunswick ore dust, at solution concentration of maximum 2%.

Table 9 - Sinkage rate of the ore dust at various reagent concentrations, Op - Opemiska; Br - Brunswick

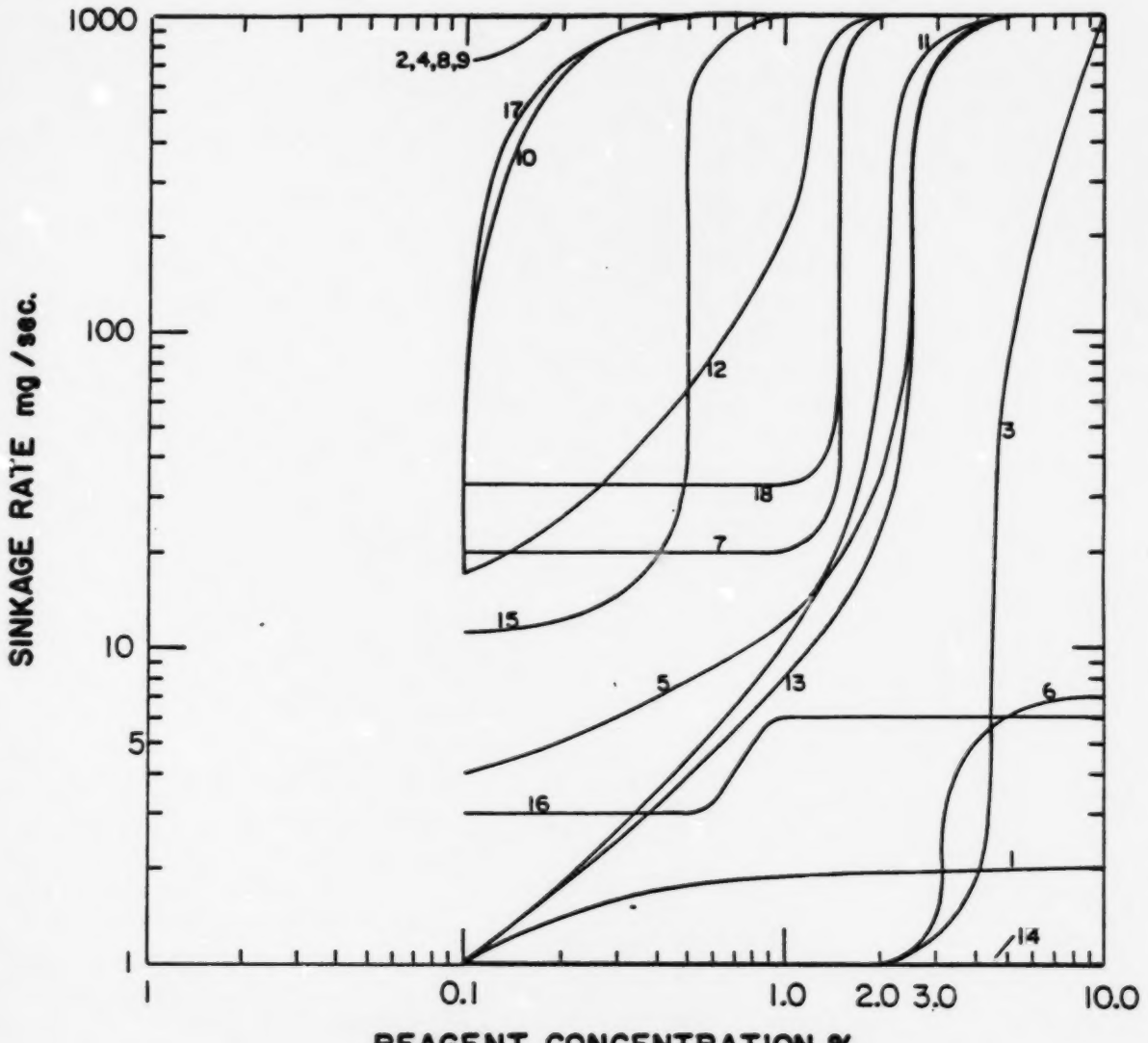
		0.1% conc		0.5% conc		1.0% conc		2.0% conc		5.0% conc		10.0% conc		25.0% conc	
		Sinkage		Sinkage		Sinkage		Sinkage		Sinkage		Sinkage		Sinkage	
			rate		rate		rate		rate		rate		rate		rate
Reagent	Ore	sec	mg/sec	sec	mg/sec	sec	mg/sec	sec	mg/sec	sec	mg/sec	sec	mg/sec	sec	mg/sec
Coherex	Op	180	6					120	8	120	8	90	11	60	17
	Br	>900	<1					600	2	540	2	420	2	300	3
Antarox	Op	1	1000	1	1000	1	1000	1	1000						
Co-610	Br	1	1000	1	1000	1	1000	1	1000						
Tergitol	Op	>900	<1					300	3	15	67	1	1000		
08	Br	>900	<1					>900	<1	15	67	1	1000		
Sterling	Op	1	1000	1	1000	1	1000	1	1000						
NP10	Br	1	1000	1	1000	1	1000	1	1000						
Sterling	Op	15	67					1	1000	1	1000				
AOS	Br	240	4					30	33	1	1000				
Sterling	Op	>900	<1					>900	<1	90	11	90	11		
Snow White	Br	>900	<1					>900	<1	180	6	150	7		
Aerosol	Op	3	333	2	500	1	1000	1	1000	1	1000				
OT-100	Br	5	200	5	200	5	200	1	1000	1	1000				
Aerosol	Op	1	1000	1	1000	1	1000	1	1000						
OT-S	Br	1	1000	1	1000	1	1000	1	1000						
Aerosol	Op	1	1000	1	1000	1	1000	1	1000						
OPG	Br	1	1000	1	1000	1	1000	1	1000						
Ethomeen	Op	1	1000	1	1000	1	1000	1	1000						
C/15	Br	15	67	1	1000	1	1000	1	1000						
Armak	Op	180	6					15	67	1	1000				
CES 372	Br	>900	<1					15	67	1	1000				
Armak	Op	30	33	10	100	2	500	1	1000	1	1000				
CEA 255	Br	60	17	15	67	5	200	1	1000	1	1000				
Dow	Op	120	8			20	50	10	100	1	1000				
Q4-3667	Br	>900	<1			120	8	45	22	1	1000				
Dow	Op	60	17			25	40	10	100	1	1000	1	1000		
HV-490	Br	>900	<1			1200	<1	1200	<1	1200	<1	1200	<1		
Dow E-2943	Op	60	17	5	200	1	1000	1	1000						
145-1	Br	90	11	30	33	1	1000	1	1000						
Dow E-2943	Op	45	22	40	25	15	67	15	67						
145-2	Br	300	3	300	3	180	6	180	6						
Dow E-2943	Op	15	67	1	1000	1	1000								
145-3	Br	60	17	1	1000	1	1000								
Dow E-2943	Op	3	333			1	1000	1	1000						
145-4	Br	30	33			30	33	1	1000						

Fig. 4 - Dust (Opemiska ore) sinkage rate as function of the reagent concentration



1. Coherex
2. Antarox CO-610
3. Tergitol 08
4. Sterling NP10
5. Sterling AOS
6. Sterling Snow White
7. Aerosol OT-100
8. Aerosol OT-S
9. Aerosol GPG
10. Ethomeen C/15
11. Armak CES 372
12. Armak CES 265
13. Dow Q4-3667
14. Dow HV-490
15. Dow E-2943-145-1
16. Dow E-2943-145-2
17. Dow E-2943-145-3
18. Dow E-2943-145-4

Fig. 5 - Dust (Brunswick ore) sinkage rate as function of the reagent concentration.



1. Coherex
2. Antarox CO-610
3. Tergitol 08
4. Sterling NP10
5. Sterling AOS
6. Sterling Snow White
7. Aerosol OT-100
8. Aerosol OT-S
9. Aerosol GPG
10. Ethomeen C/15
11. Armak CES 372
12. Armak CES 265
13. Dow Q4-3667
14. Dow HV-490
15. Dow E-2943-145-1
16. Dow E-2943-145-2
17. Dow E-2943-145-3
18. Dow E-2943-145-4

The following surfactants met this condition:

- Antarox CO-610
- Sterling NP-10
- Aerosol OT-100
- Aerosol OT-S
- Aerosol GPG
- Ethomeen C/15
- Armak CES-372
- Armak CES-265
- Dow E-2943-145-1
- Dow E-2943-145-3
- Dow E-2943-145-4

The sinkage rate of Opemiska and Brunswick ore dust for all but one of these surfactants, at concentration between 0.1 and 2% was in the 1000 mg/s range. Although Armak CES-372 exhibited less wetting ability than most of those retained in the selected group, it was still included in this category because it allowed sinkage rate superior to that of those that were eliminated.

It is interesting to mention that the Institute of Hygiène des Mines, in Hasselt, Belgium carried out, many years ago, intensive testwork to evaluate and select surfactants suitable for dust suppression. They tested wetting agents produced in Europe and USA and at that time it was considered that a product apt to be used as dust suppressant should meet the following requirements, when tested as 0.1% solution: surface tension inferior to 35 dynes/cm and sinkage rate of -74 microns dust, greater than 3 mg/s for coal and 12 mg/s for rock (3).

On the basis of the sinkage rate evaluation it is obvious that the surfactants selected by our testwork showed better ability to wet the ore dust than those tried in Belgium.

Tests to Evaluate the Volume and Persistency of the Foam Produced by the Surfactants

Excessive and/or presistent froth produced by the surfactants when mixed with water is an undesirable condition for dust suppression and further processing of the ore in the mill.

The presence of the foam impedes a good spreading of the wetting agents on the surface of the fine particles reducing thus the efficiency of dust suppression. Also, the frothy wetting agents adhering on the surface of the ore particles and carried with them to the mill would generate excessive foam in any wet process, particularly flotation, adversely affecting the selectivity in the separation and recovery of mineral values.

Therefore producing excessive and/or persistent foam was regarded as a negative characteristic of the surfactants for our particular application.

The surfactants were tested for the following two foaming properties: foam maximum volume and foam persistency.

The foam maximum volume was evaluated by placing in a graduated test tube, 20 mL of reagent solution at various concentrations (Fig. 6a). The test tube was shaken until the level of the foam did not rise any higher. Then, after one minute rest the height of the foam column (above the 20 mL level) was measured and reported as the foam maximum volume, for that particular condition (Fig. 6b). Also, the ratio between the froth maximum volume and the initial volume of the solution before shaking was calculated, to obtain a nondimension index characterizing the foaming power of the tested surfactants.

The results of the foam maximum volume determinations are presented in Table 10 and Fig. 7.

The foam persistency of the surfactants was determined by measuring the variation of the foam volume level, in the test tube, at successive time intervals. The ratio between the froth volume at various time intervals and the maximum froth volume was calculataed and used as a comparison index to characterize the stability of the foam.

The results of the foam persistency determinations, for reagents solution of 2% concentration are given in Table 11 and Fig. 8.

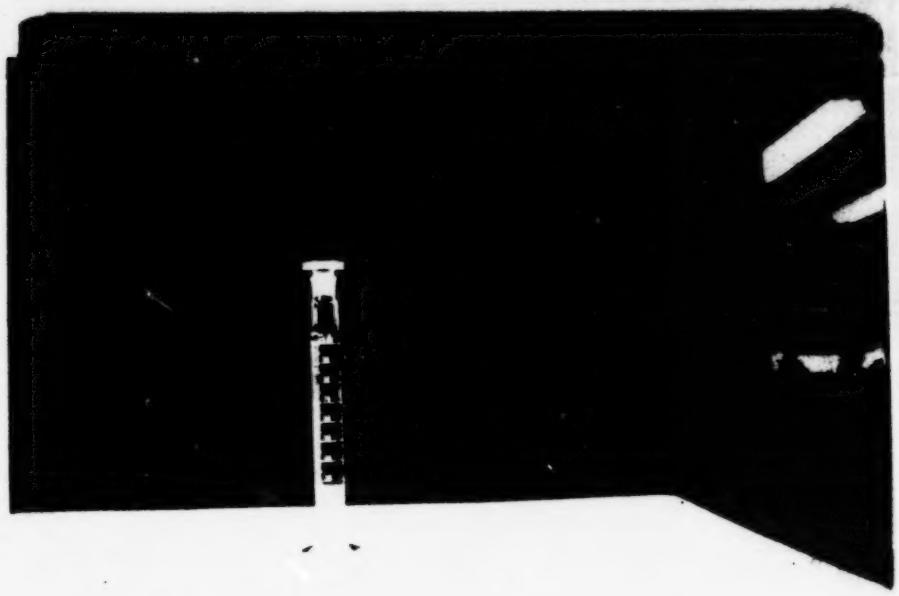


Fig. 6(a)

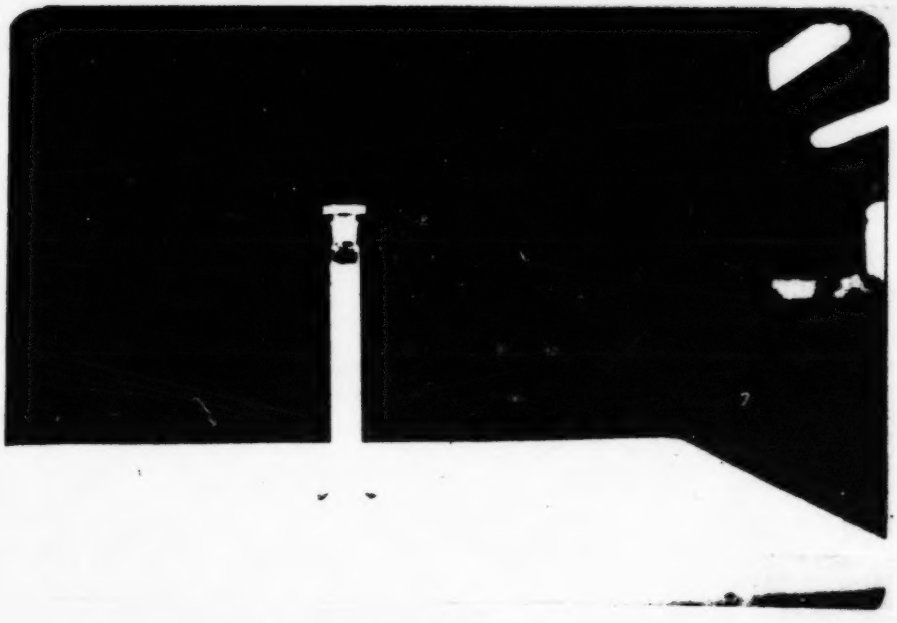


Fig. 6(b)

Laboratory procedure used to determine the surfactant foam volume and persistency. Surfactant solution in a test tube before shaking to produce foam (a) and after shaking with foam above the solution level (b)

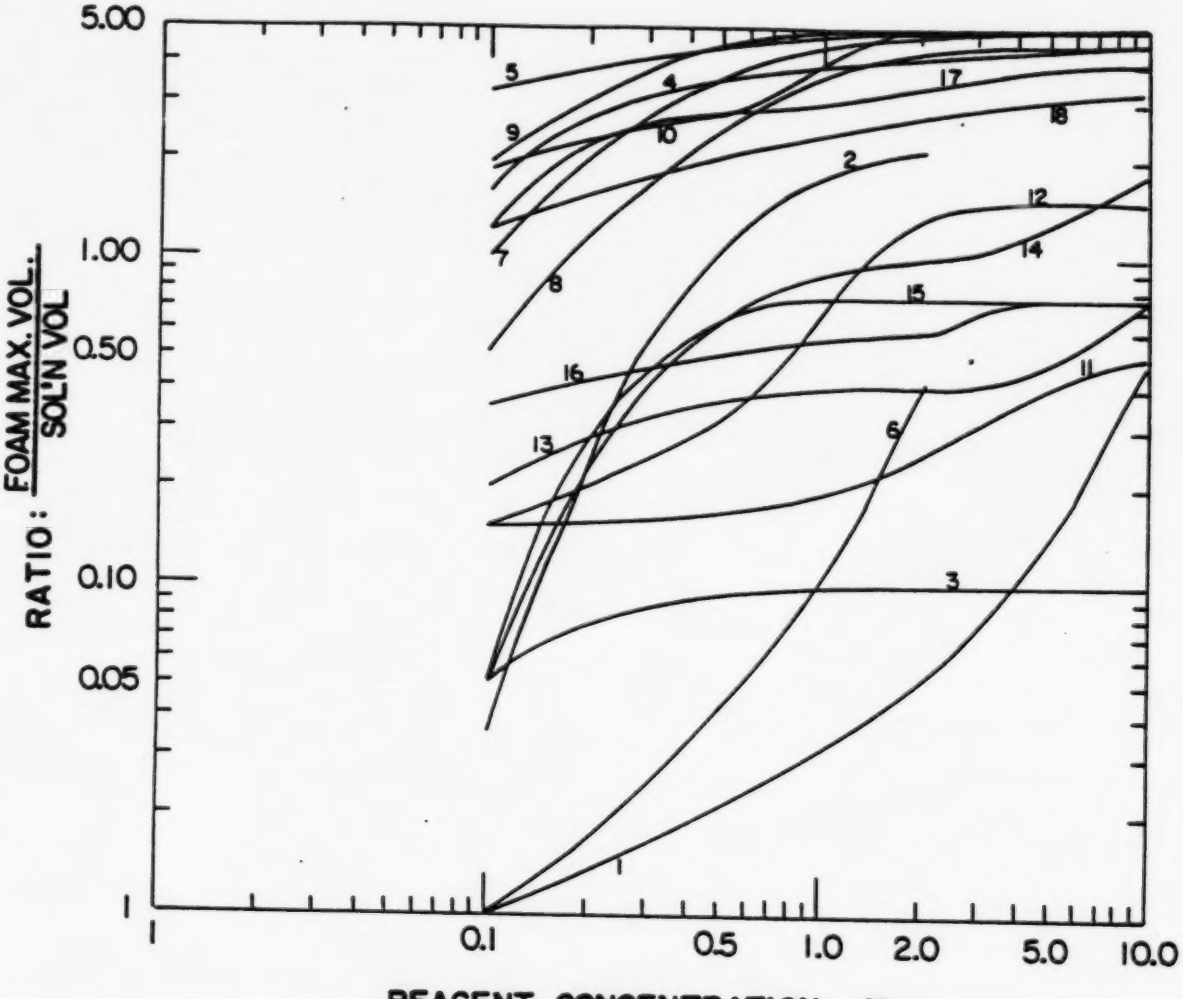
Table 10 - Foam maximum volume at various reagent concentrations

(Foam level after 1 minute rest)

		0.1% conc		0.5% conc		1.0% conc		2.0% conc		5.0% conc		10.0% conc	
No.	Reagent	Max vol mL	Ratio (vol) foam sol'n	Max vol mL	Ratio (vol) foam sol'n	Max vol mL	Ratio (vol) foam sol'n	Max vol mL	Ratio (vol) foam sol'n	Max vol mL	Ratio (vol) foam sol'n	Max vol mL	Ratio (vol) foam sol'n
1	Coherex	0	0.00					1	0.05	4	0.20	7	0.35
2	Antarox CO-610	7	0.35			35	1.75	43	2.15	27	1.35	*15	0.75
3	Tergitol 08	1	0.05					2	0.10	2	0.10	2	0.10
4	Sterling NP10	32	1.60			77	3.85	80	4.00			90	4.50
5	Sterling AOS	64	3.20			95	4.75	100	5.00			105	5.25
6	Sterling Snow White	0	0.00			2	0.10	8	0.40			*0	0.00
7	Aerosol OT-100	20	1.00			90	4.50	100	5.00			*0	0.00
8	Aerosol OT-S	10	0.50			70	3.50	85	4.25			90	4.50
9	Aerosol GPG	38	1.90			100	5.00	100	5.00			100	5.00
10	Ethomeen C/15	37	1.85	54	2.70			100	5.00			100	5.00
11	Armak CES 372	3	0.15					5	0.25	8	0.40	10	0.50
12	Armak CES 265	3	0.15			13	0.65	25	1.25			30	1.50
13	Dow Q4-3667	4	0.20			8	0.40	8	0.40	10	0.50	15	0.75
14	Dow HV-490	1	0.05			18	0.90	20	1.00			37	1.85
15	Dow E-2943-145-1	10	0.50			15	0.75	15	0.75			15	0.75
16	Dow E-2943-145-2	7	0.35					12	0.60	15	0.75	15	0.75
17	Dow E-2943-145-3	24	1.20	55	2.75	60	3.00	67	3.35			80	4.00
18	Dow E-2943-145-4	24	1.20			47	2.35	54	2.70			65	3.25

* Froth becomes thicker and reduces its volume

Fig. 7 - Ratio foam: solution (by volume) as function of the surfactant concentration

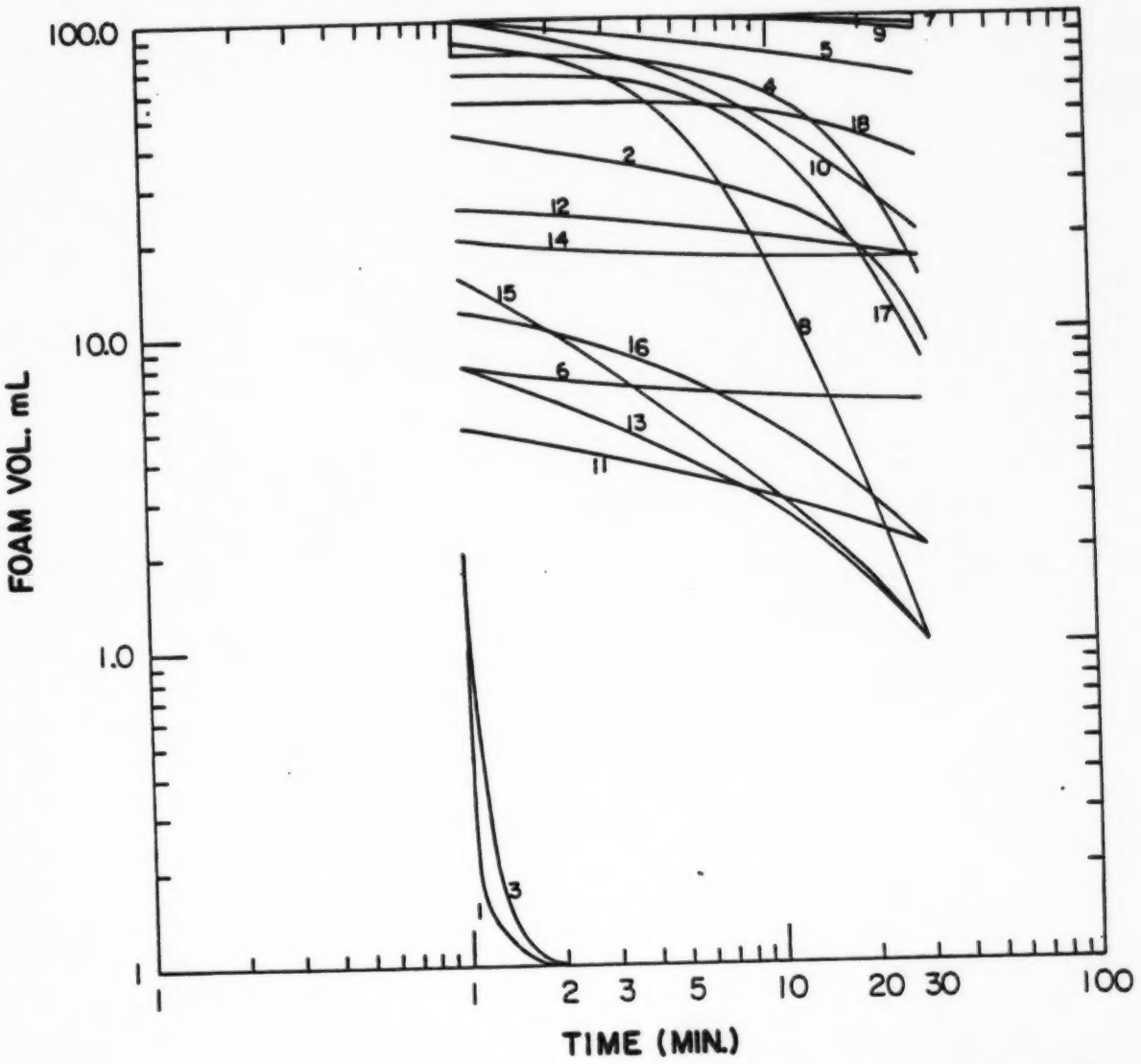


1. Cpherex
2. Antarox CO-610
3. Tergitol 08
4. Sterling NP10
5. Sterling AOS
6. Sterling Snow White
7. Aerosol OT-100
8. Aerosol OT-S
9. Aerosol GPG
10. Ethomeen C/15
11. Armak CES 372
12. Armak CES 265
13. Dow Q4-3667
14. Dow HV-490
15. Dow E-2943-145-1
16. Dow E-2943-145-2
17. Dow E-2943-145-3
18. Dow E-2943-145-4

Table 11 - Foam persistency at 2% reagents concentration

		1 min		2 min		3 min		5 min		10 min		20 min		30 min	
	Reagent (2% conc)	Foam vol mL	Ratio (vol) foam 1 min / foam 1 min	Foam vol mL	Ratio (vol) foam 2 min / foam 1 min	Foam vol mL	Ratio (vol) foam 3 min / foam 1 min	Foam vol mL	Ratio (vol) foam 5 min / foam 1 min	Foam vol mL	Ratio (vol) foam 10 min / foam 1 min	Foam vol mL	Ratio (vol) foam 20 min / foam 1 min	Foam vol mL	Ratio (vol) foam 30 min / foam 1 min
1	Coherex	1	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
2	Antarox CO-610	43	1.00	38	0.88	35	0.81	32	0.74	25	0.58	20	0.47	10	0.23
3	Tergitol 08	2	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
4	Sterling NP10	80	1.00	77	0.96	75	0.94	72	0.90	70	0.88	30	0.38	15	0.19
5	Sterling AOS	100	1.00	95	0.95	90	0.90	80	0.80	75	0.75	70	0.70	65	0.65
6	Sterling Snow White	8	1.00	8	1.00	7	0.88	7	0.88	6	0.75	6	0.75	6	0.75
7	Aerosol OT-100	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00	95	0.95	90	0.90
8	Aerosol OT-S	85	1.00	75	0.88	65	0.76	45	0.53	15	0.18	3	0.04	1	0.01
9	Aerosol GPG	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00	90	0.90	90	0.90
10	Ethomeen C/15	100	1.00	95	0.95	80	0.80	65	0.65	45	0.45	30	0.30	20	0.20
11	Armak CES 372	5	1.00	4	0.80	4	0.80	4	0.80	3	0.60	3	0.60	2	0.40
12	Armak CES 265	25	1.00	24	0.96	23	0.92	20	0.80	20	0.80	18	0.72	17	0.68
13	Dow QA-3667	8	1.00	6	0.75	5	0.63	4	0.50	2	0.25	2	0.25	1	0.13
14	Dow HV-490	20	1.00	19	0.95	19	0.95	18	0.90	17	0.85	17	0.85	17	0.85
15	Dow E-2943-145-1	15	1.00	10	0.67	6	0.40	5	0.33	3	0.20	2	0.13	1	0.07
16	Dow E-2943-145-2	12	1.00	10	0.83	8	0.67	6	0.50	5	0.42	4	0.33	2	0.17
17	Dow E-2943-145-3	67	1.00	65	0.97	64	0.96	62	0.93	60	0.90	10	0.15	8	0.12
18	Dow E-2943-145-4	54	1.00	54	1.00	53	0.98	53	0.98	50	0.93	40	0.74	35	0.65

Fig. 8 - Persistency of the surfactant foam volume as function of time



1. Coherex
2. Antarox CO-610
3. Tergitol 08
4. Sterling NP10
5. Sterling AOS
6. Sterling Snow White
7. Aerosol OT-100
8. Aerosol OT-S
9. Aerosol GPG
10. Ethomeen C/15
11. Armak CES 372
12. Armak CES 265
13. Dow Q4-3667
14. Dow HV-490
15. Dow E-2943-145-1
16. Dow E-2943-145-2
17. Dow E-2943-145-3
18. Dow E-2943-145-4

Almost all the reagents diluted in water and subjected to shaking in the test tube generated various amounts of foam which in many cases were quite persistent over a period of 30 minutes. The exceptions were Coherex and Tergitol 08 which produced very little froth which disappeared after 2 minutes of resting. Reduced amounts of foam also occurred in the tests with Armak CES 372 and some of the Dow reagents while Aerosol OT-S and Dow E-2943-145-1 generated the least stable froth (except for Coherex and Tergitol).

Based on the determinations characterizing the volume and persistency of the foam produced by the surfactants, the following reagents: Sterling AOS and Snow White, Aerosol OT-100 and GPG, Armak CES-265, Dow HV-490 and E-2943-145-4 should be given low rate in the selection as potential dust suppressors due to their high foaming properties.

Other Criteria to Select the Surfactants as Dust Suppressors

The selection of the surfactants as potential sulphide dust suppressors was also based on their response to the following two requirements:

- good solubility at ambient temperature,
- safe handling and operating conditions.

Table 12 presents an evaluation of the surfactants solubility based on the required stirring time to have the reagent completely dissolved in water at ambient temperature (20°C).

All the surfactants, except Aerosol OT-100 and Armak CES-265, exhibited good or fair solubility at concentrations ranging from 0.1 to 10%.

Table 13 gives a brief evaluation of the surfactants safety data in terms of health hazard information and fire or explosion risk.

This information was obtained from the material safety data sheets supplied by the various manufactures.

Based on the available safety data information it appeared that, except for Ethomeen C/15 which is a very corrosive agent, all the other surfactants present no special health, flammable or combustible hazard, thus requiring no special precautions in handling, storage or operation. Because Dow reagents have not been assessed yet, they cannot be evaluated from the safety point of view.

Table 12 - Evaluation of surfactants solubility

	0.1% conc		0.5% conc		1.0% conc		2.0% conc		5.0% conc		10.0% conc	
	Mixing minute	Solu-bility	Mixing minute	Solu-bility	Mixing minute	Solu-bility	Mixing minute	Solu-bility	Mixing minute	Solu-bility	Mixing minute	Solu-bility
Coherex	2	Good					2	Good	2	Good	2	Good
Antarox-CO-610	5	Good			5	Good	5	Good				
Tergitol 08	2	Good					2	Good	2	Good	2	Good
Sterling NP10	10	Fair	10	Fair			10	Fair				
Sterling AOS	2	Good					2	Good	2	Good		
Sterling Snow White	4	Good					4	Good	4	Good	4	Good
Aerosol OT-100	90	Poor					90	Poor				
Aerosol OT-S	2	Good					2	Good				
Aerosol GPG	3	Good					3	Good				
Ethomeen C/15	5	Good					5	Good				
Armak CES-372	3	Good					3	Good	3	Good		
Armak CES-265	70	Poor					90	Poor				
Dow Q4-3667	2	Good					2	Good	2	Good		
Dow HV-490	2	Good					2	Good	2	Good	2	Good
Dow-E-145-1	2	Good	2	Good	2	Good	2	Good				
Dow-E-145-1	4	Good					4	Good			4	Good
Dow-E-145-3	1	Good	1	Good	1	Good	1	Good				
Dow-E-145-4	3	Good			3	Good	3	Good				

Table 13 - Surfactants safety data

Surfactant	Health Hazard: Skin irritation	Health Hazard: Eye irritation	Fire and Explosion: Flammable	Fire and Explosion: Combustible	Special precautions	Safety remarks
Coherex	No	No	No	No	None	Acceptable
Antarox CO-610	Moderate	Moderate	No	No	Glasses	Acceptable
Tergitol 08	Moderate	Moderate	No	No	Glasses; gloves	Acceptable
Sterling NP10	Moderate	Moderate	No	No	Glasses; gloves	Acceptable
Sterling AOS	No	No	No	No	None	Acceptable
Sterling Snow White	-	-	-	-	-	Not available
Aerosol OT-100	Moderate	Moderate	No	No	Glasses; gloves	Acceptable
Aerosol OT-S	Moderate	Moderate	No	No	Glasses	Acceptable
Aerosol GPG	Moderate	Moderate	No	No	Glasses	Accpetable
Ethomeen C/15	Moderate	Severe	No	No	Face shield, gloves	Not acceptable (Very corrosive)
Armak CES-372	Moderate	Moderate	No	No	Glasses; gloves	Acceptable
Armak CES-265	Moderate	Moderate	No	No	Glasses; gloves	Acceptable
Dow Q4-3667	Not assessed		Not assessed		Not assessed	Not assessed
Dow HV-490	Not assessed		Not assessed		Not assessed	Not assessed
Dow E-145-1	Not assessed		Not assessed		Not assessed	Not assessed
Dow E-145-2	Not assessed		Not assessed		Not assessed	Not assessed
Dow E-145-3	Not assessed		Not assessed		Not assessed	Not assessed
Dow E-145-4	Not assessed		Not assessed		Not assessed	Not assessed

Selected Surfactants

The results of the testwork carried out to evaluate the surfactants as potential sulphide ore dust suppressors are summarized in Table 14.

Based on the response of the surfactants to various testing conditions an overall selection was made. The required mark to pass a test was in most of the cases arbitrarily chosen, dictated by the performances of the majority of the reagents with the intention to eliminate those that gave to most inferior results.

The most decisive criterion in selecting the surfactants was their ability to perform as wetting agents for sulphide ore dust, a property that was put in evidence by their sinkage rate. However, those particular reagents, which exhibited excessive foaming properties, showed very low solubility in water, or required special precautions in handling and operation were eliminated in the final selection regardless of their wetting ability.

The following surfactants were selected as potential sulphide dust suppressants:

1. Anatarox CO-610
2. Sterling NP-10
3. Aerosol OT-S
4. Aerosol GPG
5. Armak CES-372
6. Dow E-2943-145-1
7. Dow E-2943-145-3
8. Dow E-2943-145-4

The selected reagents were further subjected to an examination intended to determine their influence on the flotation process.

Table 14 - Summary of results obtained in the testwork with surfactants

		Surface tension		Sinkage		Foaming			Solubility		Safety		
	Surfact. conc			Rate, mg/s		Ratio: Max. foam	foam 30 min		Req'd mix				Overall
Surfactant	%	dyne/cm	Select	Opem./Bruns.	Select	Sol'n vol	foam 1 min	Select	minute	Select	Condition	Select	selection
Coherex	2.0	39.5	No	8 ; 2	No	0.05	0.00	Yes	2	Yes	Acceptable	Yes	Rejected
Antarox CO-610	0.1	33.4	Yes	1000 ; 1000	Yes	0.35	0.23	Yes	5	Yes	Acceptable	Yes	Accepted
Tergitol 08	2.0	44.8	No	3 ; <1	No	0.10	0.00	Yes	2	Yes	Acceptable	Yes	Rejected
Sterling NP10	0.1	34.4	Yes	1000 ; 1000	Yes	1.60	0.19	Yes	10	Yes	Acceptable	Yes	Accepted
Sterling AOS	2.0	37.1	No	1000 ; 33	No	5.00	0.65	No	2	Yes	Acceptable	Yes	Rejected
Sterling Snow White	2.0	35.5	No	<1 ; <1	No	0.40	0.75	No	4	Yes	Acceptable	Yes	Rejected
Aerosol OT-100	2.0	28.7	Yes	1000 ; 1000	Yes	5.00	0.90	No	90	No	Acceptable	Yes	Rejected
Aerosol OT-S	0.1	30.6	Yes	1000 ; 1000	Yes	0.50	0.01	Yes	2	Yes	Acceptable	Yes	Accepted
Aerosol GPG	0.1	29.6	Yes	1000 ; 1000	Yes	1.90	0.90	No	3	Yes	Acceptable	Yes	Accepted
Ethomeen C/15	0.5	35.2	No	1000 ; 1000	Yes	2.70	0.20	Yes	5	Yes	Very corrosive	No	Rejected
Armak CES-372	2.0	36.9	No	67 ; 67	Yes	0.25	0.40	Yes	3	Yes	Acceptable	Yes	Accepted
Armak CES-265	2.0	38.0	No	1000 ; 1000	Yes	1.25	0.68	No	90	No	Acceptable	Yes	Rejected
Dow Q4-3667	2.0	35.4	No	100 ; 22	No	0.40	0.13	Yes	2	Yes	Not assessed	-	Rejected
Dow HV-490	>10.0	32.1	Yes	1000 ; 1	No	1.85	0.85	No	2	Yes	Not assessed	-	Rejected
Dow E-2943-145-1	1.0	29.0	Yes	1000 ; 1000	Yes	0.75	0.07	Yes	2	Yes	Not assessed	-	Accepted
Dow E-2943-145-2	2.0	36.8	No	67 ; 6	No	0.75	0.17	Yes	4	Yes	Not assessed	-	Rejected
Dow E-2943-145-3	0.5	25.5	Yes	1000 ; 1000	Yes	2.75	0.12	Yes	1	Yes	Not assessed	-	Accepted
Dow E-2943-145-4	2.0	32.6	Yes	1000 ; 1000	Yes	2.70	0.65	No	3	Yes	Not assessed	-	Accepted
Required value for selection	<5.0	<35.0		>67 ; >67		<2.75	<0.40		<10		Normal precaution		

TESTWORK TO EVALUATE THE INFLUENCE OF THE WETTING AGENTS ON THE FLOTATION RESULTS

The ore samples, Opemiska and Brunswick, from which the dust for the sinkage tests was obtained were also used to examine, in laboratory scale, the influence of the surfactants on the flotation process.

To simulate the exposure of the ore to the wetting agents used as dust suppressants in the underground mining operations, the surfactants were added to the dry samples prior to the grinding stage. Solutions of 2% concentration in wetting agent were used and the amount of added solution was varied between 2.5 and 50 L/t of ore [few tens of litres of solution per ton of ore is considered an adequate spray to suppress the underground dust (1)].

After grinding, the slurry containing the surfactants was transferred to a flotation cell and the flotation was performed under the conditions established for each of the two ore samples. The flotation results with and without surfactants addition were compared.

Following are the results of the tests carried out to determine the influence of the selected surfactants on the flotation of Opemiska and Brunswick ore.

OPEMISKA COPPER ORE

The ore processed by the Opemiska Division of Falconbridge Copper Limited contains chalcopyrite and pyrite as the main sulphide minerals. This ore represents a material of low sulphides content and the technological process involves collective flotation for the recovery of one mineral only.

The head assay of the Opemiska ore sample used for the flotation experiments is given below:

Constituent	Assay %
Cu	4.39
Pb	0.02
Zn	0.08
S	5.27
SiO_2	41.83
Fe	15.98

Several tests were first carried out, without surfactants additon, to determine the copper flotation conditions under which, results (concentrate grade and recovery) similar to those produced in the industrial scale can be obtained.

To simplify the testwork the copper flotation was limited to an open rougher-scavenger circuit with the rougher concentrate representing the final copper product.

The grinding and the type of flotation reagents used in this testwork were similar to those employed in Opemiska concentrator.

The following conditions were established for the laboratory testwork:

Grinding: 65% -74 microns

Flotation:	Rougher	Scaveng. -1	Scaveng. -2
pH:	9.6	9.3	9.1
Reagents, g/t:			
Lime	300	-	-
Xamthate 350 (K amyl)	25	20	20
TEB (triethoxybutane)	80	80	48
Flotation time, minutes:	6.5	6	5

The complete metallurgical results of the copper flotation with and without surfactants addition are given in Appendix A.

A summary of the most significative results (Cu grade and recovery in the rougher concentrate) is presented in Table 15.

When no surfactant was used the rougher concentrate assayed 24.77% Cu and the copper recovery in this product was 94.2%.

All the surfactants tested with Opemiska ore had a detrimental effect on copper flotation by reducing the grade of the concentrate, the Cu recovery or both. The negative effect on the flotation results was in direct rapport with the amount of surfactant solution added to the ore. For some reagents (Antarox, Dow 145-4), the reduction in the Cu content of the concentrate was tolerable up to 10 L/t solution added to the ore, especially since the recovery remained high. However, at 50 L/t addition of reagent solution, the concentrate grade dropped so much that the results became unacceptable for all of the tested surfactants.

Table 15 - Summary of Opemiska ore flotation results (rougher conc)

	2.5 L/t		5.0 L/t		10.0 L/t		50.0 L/t	
Surfactant	Assay % Cu	% Recov Cu	Assay % Cu	% Recov Cu	Assay % Cu	% Recov Cu	Assay % Cu	% Recov Cu
Antarox	23.07	95.1	21.19	96.2	22.69	94.9	20.49	94.5
Sterling NP10	23.83	93.5	22.54	94.6	21.74	95.5	17.44	97.3
Aerosol OT-S	19.39	79.9	18.71	60.4	15.98	76.9	12.47	75.9
Aerosol GPG	21.10	85.1	20.81	88.5	18.27	74.7	11.78	64.7
Armak CES-372	22.35	95.5	19.00	93.4	20.34	92.6	20.43	95.1
Dow E-145-1	20.03	95.4	20.00	96.8	21.31	96.1	19.91	96.3
Dow E-145-3	21.84	96.2	21.39	97.5	20.15	98.0	19.26	95.7
Dow E-145-4	21.13	96.5	20.86	97.4	22.90	96.6	19.13	97.6

Figures 9 and 10 show a flotation test of Opemiska ore without surfactants while Fig. 11 and 12 present a flotation test in the presence of the wetting agents (50 L/kg).

Various explanations were sought for the detrimental effect of the surfactants on the flotation of Opemiska copper ore.

One of the causes for the deterioration of the concentrate grade was attributed to the excessive amount of froth produced by the surfactants. This has made the slimes and some gangue constituents to become entrained in the froth and float along with the copper minerals, diluting the Cu content of the concentrate.

It is also believed that some surfactants could have interfered, at least to some extent, with the collecting action of the flotation reagents. The selected surfactants used for the flotation experiments were classified in three groups:

- Non ionic (Antarox, Sterling NP10, Dow reagents)
- Anionic (Aerosol OT-S and GPG)
- Cationic (Armak CES-372)

It is likely that the anionic surfactants present in the slurry prior to the addition of the flotation reagents have occupied sites on the surface of the copper minerals preventing an adequate adsorption of the anionic col-

lector at the intergace water mineral. It appeared that the results presented in Table 15 supported this assumption quite well, since in the tests where Aerosol OT-S and GPG, both anionic surfactants, were used, the copper recovery was much lower than that for the experiments carried out in the presence of non-ionic or cationic agents.

A systematic testwork will be required to try to identify the causes of the surfactants interference with the flotation process and to eliminate or at least alleviate their detrimental effect on the metallurgical results.

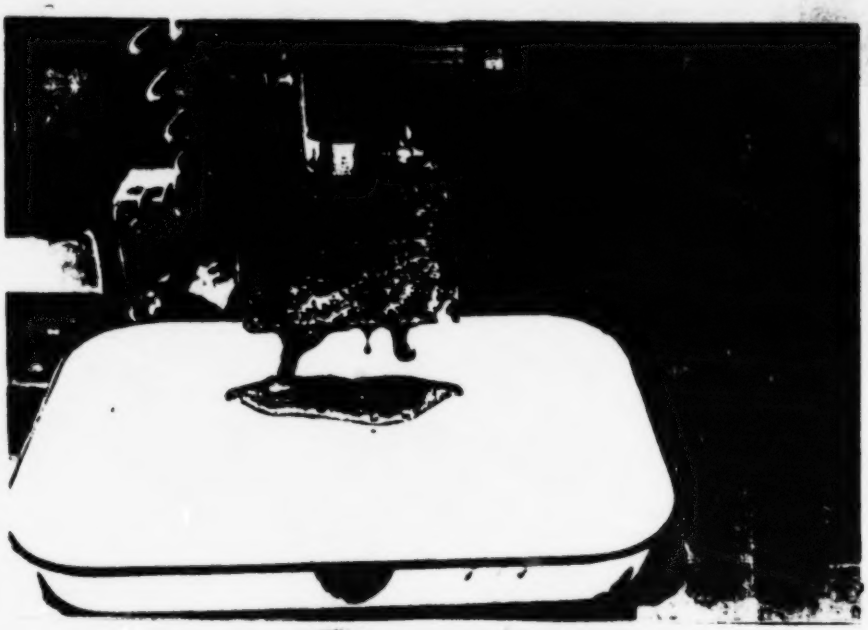


Fig. 9 - Flotation of Opemiska ore without surfactants
(beginning of the test)

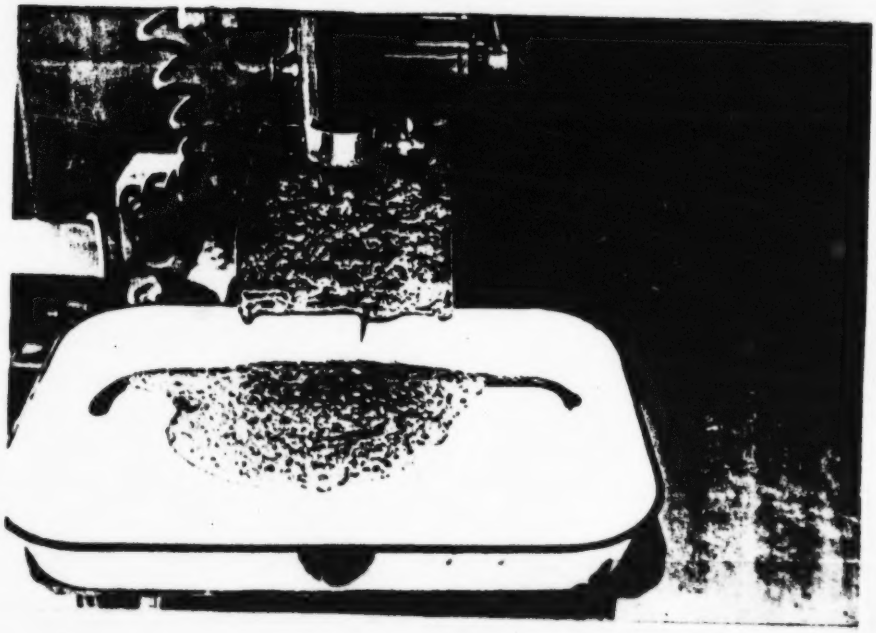


Fig. 10 - Flotation of Opemiska ore without surfactants
(in the course of the test)

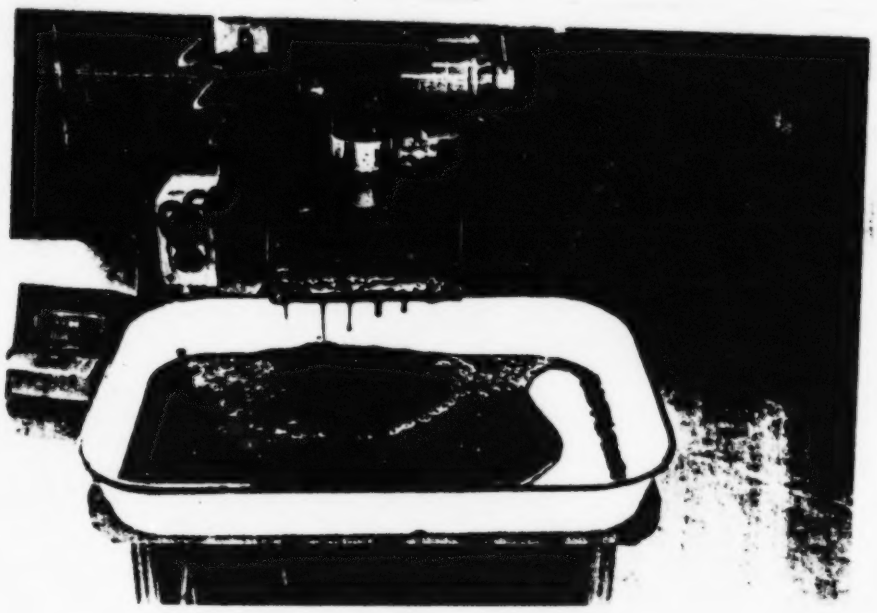


Fig. 11 - Flotation of Opemiska ore in the presence of surfactants (Sterling NP10 at 50L/t)

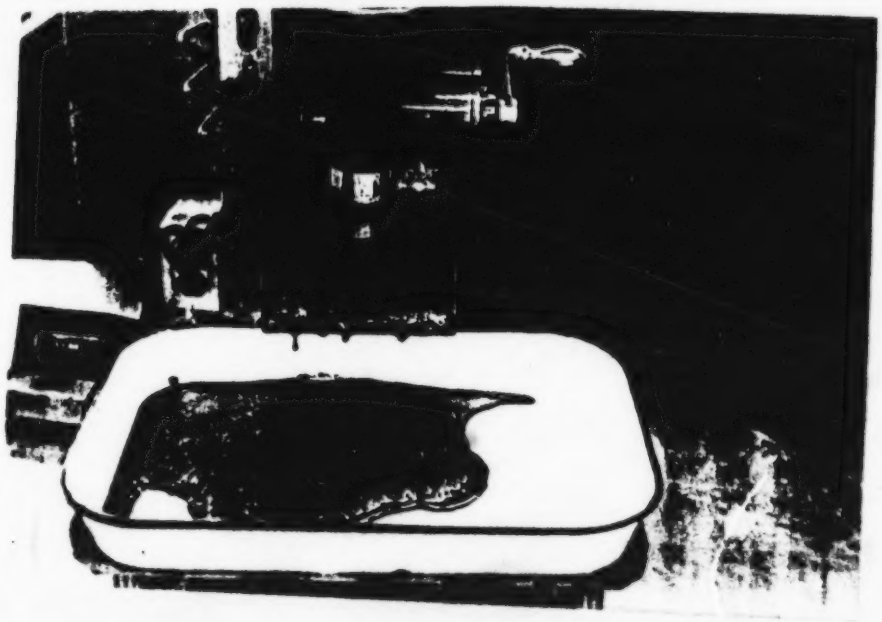


Fig. 12 - Flotation of Opemiska ore in the presence of surfactants (Dow reagents at 50L/t)

BRUNSWICK COMPLEX ORE

Brunswick ore, processed by the Brunswick Mining and Smelting Corporation is composed of approximately 80% sulphides of which pyrite is the predominant mineral with sphalerite, galena and chalcopyrite occurring as replacements in the form of high-grade and low-grade bandings.

This ore represents a material of high sulphide content and the technological process involves differential flotation for the separation of two products: Cu-Pb concentrate and Zn concentrate. In a subsequent stage the Cu-Pb concentrate is also separated into two distictive products but our testwork did not deal with the galena-chalcopyrite separation.

The head assay of the Brunswick ore sample used for the flotation experiments is presented below:

Constituent	%
Cu	0.18
Pb	5.78
Zn	14.76
S	15.88
SiO_2	31.67
Fe	17.08

A number of flotation tests were first carried out without surfactants addition to determine the laboratory conditions under which metallurgical results comparable to those obtained in the BMS concentrator can be produced.

The flowsheet applied consisted in: grinding the ore to approximately 70% -37 microns followed by 30 minutes aeration in a flotation cell. Open circuit differential flotation was then performed collecting, in the first stage, a rougher and a scavenger Pb-Cu concentrate. In the second stage the sphalerite was activated and a rougher and a scavenger Zn concentrate was collected. No Pb-Cu separation was carried out.

The following conditions were finalized for the laboratory testwork:

Grinding:	70% -37 microns
Reagents:	Na_2CO_3: 1000 g/t
	H_2SO_3: 300 g/t
	NaCN: 20 g/t
Aeration:	30 minutes

Flotation:	Pb - Cu		Zn	
	Rougher	Scavenger	Rougher	Scavenger
pH:	8.5		10.8	
Reagents, g/t:				
Lime	-	-	600	500
Copper sulfate	-	-	900	-
Xanthate 343	20	10	100	30
Xanthate 350	5	2.5	2.5	7.5
Aerofloat 241	20	10	-	-
MIBC	13	-	-	-
Flotation time, min.:	6	7	7	8

The same conditions were applied in the experiments where the influence of the surfactants on the flotation process was tested, except that the aeration stage was eliminated. The aeration could not be used in the presence of the surfactants since an uncontrolable amount of froth was produced making the flotation process impracticable.

The complete metallurgical results of th Pb + Cu and Zn flotation, with and without surfactants addition are presented in Appendix B.

A summary of the most representative results (metal content and recovery in the rougher concentrates) is presented in Table 16.

The presence of the surfactants, even without aeration, has dramatically deteriorated the flotation results, particularly the lead concentration. A small addition of wetting agent (2.5 L/t) was sufficient to destroy the sel-

ectivity and to reduce the grade of the concentrates. Since the metallurgical results worsened with the increase in surfactant addition it was decided to limit the amount of wetting agent administered to the ore to 10 L/t.

As in the case of Opemiska ore the causes for destroying the flotation selectivity and reducing the metal recoveries were attributed to the excesive foam produced by the surfactants and possible interference between the wetting agents and the flotation reagents.

Again, more in-depth testwork will be required to investigate the effect of the surfactants on the selective Pb-Zn flotation and to try to eliminate their detrimental influence.

Table 16 - Summary of Brunswick ore flotation results (rougher conc)

	2.5 L/t				5.0 L/t				10.0 L/t			
	Pb Conc		Zn Conc		Pb Conc		Zn Conc		Pb Conc		Zn Conc	
	Assay % Pb	% Recov. Pb	Assay % Zn	% Recov. Zn	Assay % Pb	% Recov. Pb	Assay % Zn	% Recov. Zn	Assay % Pb	% Recov. Pb	Assay % Zn	% Recov. Zn
Antarox	19.56	84.7	38.69	70.1	19.03	85.9	53.30	61.8	16.10	87.7	57.93	45.0
Sterling NP10	24.98	82.7	42.51	75.2	23.90	70.1	52.65	60.4	13.21	84.8	54.33	48.1
Aerosol OT-S	25.30	73.3	57.57	62.7	20.73	83.0	50.82	69.0	18.50	83.1	42.26	60.8
Aerosol GPG	25.33	70.8	51.67	65.1	21.00	74.6	52.22	68.3	16.70	82.6	45.10	53.4
Armak CES-372	23.03	83.9	40.70	72.6	18.33	92.6	47.03	61.6	15.71	89.1	51.86	48.3
Dow-145-1	21.59	89.5	46.52	66.1	19.71	91.0	45.81	66.3	17.94	77.4	51.44	55.5
Dow-145-3	25.84	79.3	48.94	72.2	19.78	83.8	54.31	63.7	14.53	89.2	48.83	46.1
Dow-145-4	23.29	90.7	53.68	65.7	19.35	91.9	41.66	66.7	18.06	73.5	54.81	56.6

Results for tests where no surfactant was used:

Pb Conc: Assay: 43.61% Pb; Recovery: 76.4% for Pb

Zn Conc: Assay: 54.72% Zn; Recovery: 74.8% for Zn

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APPENDIX A

METALLURGICAL RESULTS OF OPEMISKA ORE FLOTATION

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
None	-	Rougher conc	19.3	24.77	94.2
		Scav conc-1	2.5	7.05	3.5
		Scav conc-2	1.7	2.48	0.8
		Tailing	76.5	0.10	1.5
		Head (calc)	100.0	5.10	100.0
Antarox CO-610	2.5	Rougher conc	19.5	23.07	95.1
		Scav conc-1	1.4	7.86	2.3
		Scav conc-2	1.4	2.88	0.8
		Tailing	77.7	0.11	1.8
		Head (calc)	100.0	4.73	100.0
	5.0	Rougher conc	21.1	21.19	96.2
		Scav conc-1	1.8	4.88	1.9
		Scav conc-2	1.0	2.16	0.5
		Tailing	76.1	0.08	1.4
		Head (calc)	100.0	4.65	100.0
	10.0	Rougher conc	19.7	22.69	94.9
		Scav conc-1	2.6	5.22	2.9
		Scav conc-2	1.2	2.22	0.6
		Tailing	76.5	0.10	1.6
		Head (calc)	100.0	4.71	100.0
	50.0	Rougher conc	21.3	20.49	94.5
		Scav conc-1	3.6	5.02	3.9
		Scav conc-2	1.8	1.28	0.5
		Tailing	73.3	0.07	1.1
		Head (calc)	100.0	4.62	100.0

Surfactant 2% sol'n Type of reagent	L/t of ore	Products	% Wt	Assay % Cu	% Distn Cu
		Rougher conc	19.1	23.83	93.5
		Scav conc-1	2.4	6.10	3.0
	2.5	Scav conc-2	1.8	2.31	0.8
		Tailing	76.7	0.17	2.7
		Head (calc)	100.0	4.87	100.0
		Rougher conc	20.0	22.54	94.6
		Scav conc-1	1.9	5.41	2.2
Sterling	5.0	Scav conc-2	1.5	2.11	0.6
NP10		Tailing	76.6	0.16	2.6
		Head (calc)	100.0	4.77	100.0
		Rougher conc	20.0	21.74	95.5
		Scav conc-1	2.3	5.28	2.7
	10.0	Scav conc-2	2.1	1.42	0.6
		Tailing	75.6	0.07	1.2
		Head (calc)	100.0	4.55	100.0
		Rougher conc	13.5	23.54	70.1
		Scav conc-1	11.8	10.46	27.2
	50.0	Scav conc-2	3.1	2.43	1.7
		Tailing	71.6	0.06	1.0
		Head (calc)	100.0	4.53	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
		Rougher conc	18.9	19.39	79.9
		Scav conc-1	7.1	10.27	15.9
	2.5	Scav conc-2	2.1	5.35	2.5
		Tailing	71.9	0.11	1.7
		Head (calc)	100.0	4.60	100.0
		Rougher conc	14.7	18.71	60.4
		Scav conc-1	8.1	13.86	24.5
Aerosol	5.0	Scav conc-2	7.1	8.25	12.8
OT-S		Tailing	70.1	0.15	2.3
		Head (calc)	100.0	4.60	100.0
		Rougher conc	21.4	15.98	76.9
		Scav conc-1	5.5	10.18	12.6
	10.0	Scav conc-2	6.1	4.88	6.7
		Tailing	67.0	0.25	3.8
		Head (calc)	100.0	4.40	100.0
		Rougher conc	31.4	12.47	75.9
		Scav conc-1	8.7	8.41	14.2
	50.0	Scav conc-2	5.5	4.89	5.2
		Tailing	54.4	0.45	4.7
		Head (calc)	100.0	5.16	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
		Rougher conc	20.3	21.10	85.1
		Scav conc-1	5.4	10.28	11.0
	2.5	Scav conc-2	1.3	4.99	1.3
		Tailing	73.0	0.18	1.6
		Head (calc)	100.0	5.03	100.0
		Rougher conc	21.5	20.81	88.5
		Scav conc-1	5.0	7.20	7.1
	5.0	Scav conc-2	5.0	2.68	2.6
		Tailing	68.5	0.13	1.8
		Head (calc)	100.0	5.06	100.0
Aerosol					
G.P.G		Rougher conc	20.8	18.27	74.7
		Scav conc-1	6.0	14.68	17.3
	10.0	Scav conc-2	5.1	5.62	5.7
		Tailing	68.1	0.17	2.3
		Head (calc)	100.0	5.10	100.0
		Rougher conc	27.9	11.78	64.7
		Scav conc-1	11.8	9.51	22.1
	50.0	Scav conc-2	5.2	7.95	8.1
		Tailing	55.1	0.47	5.1
		Head (calc)	100.0	5.08	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
Armak CES-372	2.5	Rougher conc	18.8	22.35	95.5
		Scav conc-1	2.6	5.35	3.2
		Scav conc-2	2.4	1.00	0.6
		Tailing	76.2	0.04	0.7
		Head (calc)	100.0	4.40	100.0
	5.0	Rougher conc	20.8	19.00	93.4
		Scav conc-1	1.8	6.77	2.9
		Scav conc-2	1.8	5.74	2.4
		Tailing	75.6	0.07	1.3
		Head (calc)	100.0	4.23	100.0
	10.0	Rougher conc	19.7	20.34	92.6
		Scav conc-1	3.4	4.79	3.8
		Scav conc-2	1.9	5.90	2.6
		Tailing	75.0	0.06	1.0
		Head (calc)	100.0	4.33	100.0
	50.0	Rougher conc	20.6	20.43	95.1
		Scav conc-1	3.7	3.07	2.6
		Scav conc-2	1.7	3.02	1.1
		Tailing	74.0	0.07	1.2
		Head (calc)	100.0	4.43	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
		Rougher conc	23.0	20.03	95.4
		Scav conc-1	2.0	7.49	3.1
	2.5	Scav conc-2	1.9	1.36	0.6
		Tailing	73.1	0.06	0.9
		Head (calc)	100.0	4.82	100.0
		Rougher conc	23.1	20.00	96.8
		Scav conc-1	2.2	4.66	2.2
	5.0	Scav conc-2	1.3	1.05	0.3
		Tailing	73.4	0.05	0.7
		Head (calc)	100.0	4.77	100.0
Dow					
E-2943-145-1		Rougher conc	20.8	21.31	96.1
		Scav conc-1	2.0	3.65	1.6
	10.0	Scav conc-2	1.8	1.05	0.4
		Tailing	75.4	0.12	1.9
		Head (calc)	100.0	4.61	100.0
		Rougher conc	22.2	19.91	96.3
		Scav conc-1	2.6	4.14	2.4
	50.0	Scav conc-2	1.9	1.27	0.5
		Tailing	73.3	0.05	0.8
		Head (calc)	100.0	4.59	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
Dow E-2943-145-3	2.5	Rougher conc	20.8	21.84	96.2
		Scav conc-1	1.4	7.43	2.2
		Scav conc-2	0.9	2.40	0.5
		Tailing	76.9	0.07	1.1
		Head (calc)	100.0	4.72	100.0
	5.0	Rougher conc	21.8	21.39	97.5
		Scav conc-1	1.7	3.48	1.2
		Scav conc-2	1.0	1.48	0.3
		Tailing	75.5	0.06	1.0
		Head (calc)	100.0	4.78	100.0
	10.0	Rougher conc	22.9	20.15	98.0
		Scav conc-1	1.6	2.94	1.0
		Scav conc-2	0.8	1.05	0.2
		Tailing	74.7	0.05	0.8
		Head (calc)	100.0	4.71	100.0
	50.0	Rougher conc	23.9	19.26	95.7
		Scav conc-1	2.4	6.15	3.1
		Scav conc-2	1.8	1.36	0.5
		Tailing	71.9	0.05	0.7
		Head (calc)	100.0	4.81	100.0

Surfactant 2% sol'n		Products	% Wt	Assay	% Distn
Type of reagent	L/t of ore			% Cu	Cu
		Rougher conc	21.6	21.13	96.5
		Scav conc-1	1.9	5.33	2.1
	2.5	Scav conc-2	1.4	1.40	0.4
		Tailing	75.1	0.06	1.0
		Head (calc)	100.0	4.73	100.0
		Rougher conc	22.0	20.86	97.4
		Scav conc-1	1.9	3.75	1.5
	5.0	Scav conc-2	1.3	1.21	0.3
		Tailing	74.7	0.05	0.8
		Head (calc)	100.0	4.73	100.0
Dow					
E-2943-145-4		Rougher conc	19.9	22.90	96.6
		Scav conc-1	1.8	4.20	1.6
	10.0	Scav conc-2	2.0	1.44	0.6
		Tailing	76.3	0.07	1.2
		Head (calc)	100.0	4.72	100.0
		Rougher conc	24.5	19.13	97.6
		Scav conc-1	5.5	1.58	1.8
	50.0	Scav conc-2	1.7	0.49	0.2
		Tailing	68.3	0.03	0.4
		Head (calc)	100.0	4.80	100.0

APPENDIX B

METALLURGICAL RESULTS OF BRUNSWICK ORE FLOTATION

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	9.9	43.61	1.01	12.54	76.4	59.6	8.4
		Pb scav conc	5.0	11.97	0.32	21.94	10.6	9.5	7.5
		Zn ro conc	20.1	1.46	0.10	54.72	5.2	11.9	74.8
None	-	Zn scav conc	13.5	1.49	0.08	7.50	3.6	6.6	6.9
		Tailing	51.5	0.47	0.04	0.68	4.2	12.4	2.4
		Head (calc)	100.0	5.65	0.17	14.70	100.0	100.0	100.0
		Pb ro conc	9.5	9.40	0.31	7.22	15.8	12.8	4.7
		Pb scav conc	15.0	25.99	0.96	16.46	68.8	61.6	16.8
	2.5	Zn ro conc	26.7	1.52	0.09	38.69	7.2	10.7	70.1
		Zn scav conc	8.9	2.73	0.13	9.84	4.3	5.1	5.9
		Tailing	39.9	0.55	0.06	0.93	3.9	9.8	2.5
		Head (calc)	100.0	5.66	0.23	14.73	100.0	100.0	100.0
		Pb ro conc	21.1	18.72	0.43	8.62	61.1	41.4	13.9
		Pb scav conc	8.1	19.85	0.68	19.14	24.8	25.0	11.8
Antarox	5.0	Zn ro conc	15.2	2.19	0.21	53.30	5.1	14.5	61.8
CO-610		Zn scav conc	10.4	3.09	0.15	11.54	5.0	7.3	9.2
		Tailing	45.2	0.57	0.06	0.97	4.0	11.8	3.3
		Head (calc)	100.0	6.47	0.22	13.11	100.0	100.0	100.0
		Pb ro conc	38.7	16.10	0.40	13.35	87.7	68.3	36.1
		Pb scav conc	6.5	6.63	0.29	18.31	6.1	8.4	8.3
	10.0	Zn ro conc	11.1	1.19	0.17	57.93	1.9	8.4	45.0
		Zn scav conc	4.1	1.93	0.27	23.92	1.1	4.8	6.9
		Tailing	39.6	0.31	0.58	1.33	3.2	10.1	3.7
		Head (calc)	100.0	7.10	0.22	14.29	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	10.6	23.27	0.61	8.42	42.8	31.3	6.0
		Pb scav conc	8.5	27.10	0.92	17.53	39.9	37.5	10.0
		Zn ro conc	26.2	2.19	0.11	42.51	9.9	13.9	75.2
	2.5	Zn scav conc	12.5	1.69	0.09	6.98	3.7	5.3	5.9
		Tailing	42.2	0.51	0.06	1.01	3.7	12.0	2.9
		Head (calc)	100.0	5.77	0.21	14.82	100.0	100.0	100.0
		Pb ro conc	23.9	19.39	0.46	9.79	70.1	51.6	16.0
		Pb scav conc	8.6	15.93	0.53	22.66	20.7	21.3	13.3
Sterling	5.0	Zn ro conc	16.8	1.33	0.13	52.65	3.4	9.9	60.4
NP10		Zn scav conc	9.0	2.08	0.14	12.08	2.8	5.6	7.4
		Tailing	41.7	0.47	0.06	1.04	3.0	11.6	2.9
		Head (calc)	100.0	6.61	0.21	14.65	100.0	100.0	100.0
		Pb ro conc	38.6	13.21	0.32	13.66	84.8	74.2	36.2
		Pb scav conc	5.4	8.28	0.14	20.59	7.5	4.8	7.7
	10.0	Zn ro conc	12.9	1.41	0.10	54.33	3.0	7.8	48.1
		Zn scav conc	4.3	2.28	0.14	16.50	1.6	3.6	4.9
		Tailing	38.8	0.48	0.04	1.16	3.1	9.6	3.1
		Head (calc)	100.0	6.01	0.17	14.56	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	16.9	25.30	0.53	15.02	73.3	52.3	17.1
		Pb scav conc	7.5	11.32	0.39	18.92	14.6	17.1	9.5
		Zn ro conc	16.2	1.40	0.10	57.57	3.9	9.4	62.7
	2.5	Zn scav conc	15.7	1.48	0.09	7.99	3.9	8.2	8.4
		Tailing	43.7	0.57	0.05	0.79	4.3	13.0	2.3
		Head (calc)	100.0	5.83	0.17	14.88	100.0	100.0	100.0
		Pb ro conc	12.0	24.44	0.50	13.48	50.2	33.5	10.9
		Pb scav conc	11.4	16.84	0.56	18.91	32.8	35.8	14.5
Aerosol	5.0	Zn ro conc	20.2	2.36	0.12	50.82	8.1	13.4	69.0
OT-S		Zn scav conc	9.0	2.39	0.13	7.71	3.7	6.7	4.7
		Tailing	47.4	0.64	0.04	0.29	5.2	10.6	0.9
		Head (calc)	100.0	5.85	0.18	14.87	100.0	100.0	100.0
		Pb ro conc	26.9	18.50	0.50	15.40	83.1	73.4	27.5
		Pb scav conc	4.1	9.65	0.24	19.17	6.6	5.3	5.2
	10.0	Zn ro conc	21.6	1.15	0.08	42.26	4.1	9.3	60.8
		Zn scav conc	11.5	1.25	0.07	5.42	2.4	4.4	4.1
		Tailing	35.9	0.64	0.04	0.93	3.8	7.6	2.2
		Head (calc)	100.0	5.99	0.18	15.01	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
Aerosol GPG	2.5	Pb ro conc	16.6	25.33	0.57	14.94	70.8	54.0	17.0
		Pb scav conc	8.6	11.18	0.36	18.38	16.2	17.6	10.8
		Zn ro conc	18.4	1.64	0.10	51.67	5.1	10.2	65.1
		Zn scav conc	7.5	2.23	0.11	8.64	2.8	4.6	4.4
		Tailing	48.9	0.62	0.05	0.81	5.1	13.6	2.7
		Head (calc)	100.0	5.94	0.18	14.61	100.0	100.0	100.0
	5.0	Pb ro conc	15.2	20.55	0.35	13.54	52.6	29.8	14.1
		Pb scav conc	5.9	22.14	0.65	17.52	22.0	21.3	7.1
		Zn ro conc	19.1	3.59	0.17	52.22	11.5	18.0	68.3
		Zn scav conc	4.8	5.66	0.33	18.91	4.6	9.0	6.2
		Tailing	55.0	1.01	0.07	1.13	9.3	21.9	4.3
		Head (calc)	100.0	5.94	0.18	14.60	100.0	100.0	100.0
	10.0	Pb ro conc	28.8	16.70	0.41	14.00	82.6	63.8	26.8
		Pb scav conc	6.3	6.28	0.28	16.26	6.8	9.7	6.8
		Zn ro conc	17.8	1.16	0.12	45.10	3.6	11.4	53.4
		Zn scav conc	12.4	1.70	0.09	8.99	3.6	5.9	7.5
		Tailing	34.7	0.57	0.05	2.37	3.4	9.2	5.5
		Head (calc)	100.0	5.82	0.19	15.02	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	7.6	18.52	0.53	9.84	24.1	17.3	5.1
		Pb scav conc	13.7	25.53	0.90	14.78	59.8	53.3	13.7
		Zn ro conc	26.3	1.68	0.13	40.70	7.6	14.7	72.6
	2.5	Zn scav conc	11.6	2.33	0.10	7.90	4.6	5.2	6.0
		Tailing	40.8	0.56	0.05	0.93	3.9	9.5	2.6
		Head (calc)	100.0	5.85	0.23	14.77	100.0	100.0	100.0
		Pb ro conc	16.3	21.35	0.56	9.28	53.4	48.0	10.4
		Pb scav conc	16.6	15.37	0.39	15.94	39.2	34.3	18.2
Armak	5.0	Zn ro conc	19.0	1.00	-	47.03	2.9	0.0	61.6
CES-372		Zn scav conc	9.0	1.77	0.14	11.99	2.4	6.6	7.4
		Tailing	39.1	0.34	0.05	0.90	2.1	11.1	2.4
		Head (calc)	100.0	6.51	0.18	14.53	100.0	100.0	100.0
		Pb ro conc	39.6	15.71	0.39	12.41	89.1	71.0	33.9
		Pb scav conc	6.3	7.52	0.28	25.39	6.8	8.3	11.1
	10.0	Zn ro conc	13.3	1.03	0.15	51.86	2.0	9.2	48.3
		Zn scav conc	5.1	1.46	0.15	13.25	1.1	3.7	4.7
		Tailing	35.7	0.22	0.05	0.83	1.0	7.8	2.0
		Head (calc)	100.0	6.99	0.22	14.48	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	10.9	20.85	0.58	8.86	37.8	15.1	6.5
		Pb scav conc	14.0	22.16	0.76	18.04	51.7	25.2	17.1
		Zn ro conc	21.0	1.32	0.13	46.52	4.6	6.4	66.1
	2.5	Zn scav conc	13.3	1.65	0.12	9.09	3.7	3.8	8.2
		Tailing	40.8	0.33	0.05	0.77	2.2	49.5	2.1
		Head (calc)	100.0	5.86	0.42	14.72	100.0	100.0	100.0
		Pb ro conc	16.9	19.13	0.47	8.44	53.3	40.7	9.7
		Pb scav conc	11.1	20.60	0.68	20.42	37.7	38.7	15.3
Dow	5.0	Zn ro conc	21.4	1.19	0.07	45.81	4.2	7.2	66.3
E-2943-145-1		Zn scav conc	10.8	1.57	0.10	8.81	2.8	5.7	6.4
		Tailing	39.8	0.31	0.04	0.84	2.0	7.7	2.3
		Head (calc)	100.0	6.07	0.19	14.78	100.0	100.0	100.0
		Pb ro conc	28.6	17.94	0.43	10.03	77.4	60.4	19.7
		Pb scav conc	6.8	15.36	0.49	23.79	15.7	16.2	11.1
	10.0	Zn ro conc	15.7	1.19	0.10	51.44	2.8	7.8	55.5
		Zn scav conc	9.8	1.56	0.16	16.07	2.3	7.8	10.8
		Tailing	39.1	0.31	0.04	1.08	1.8	7.8	2.9
		Head (calc)	100.0	6.64	0.20	14.56	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	7.9	16.31	0.45	8.39	21.9	17.8	4.5
		Pb scav conc	10.1	33.31	0.82	15.03	57.4	41.1	10.2
		Zn ro conc	21.8	2.44	0.16	48.94	9.1	17.3	72.2
	2.5	Zn scav conc	12.0	2.91	0.16	12.17	5.9	9.4	9.9
		Tailing	48.2	0.70	0.06	0.99	5.7	14.4	3.2
		Head (calc)	100.0	5.87	0.20	14.79	100.0	100.0	100.0
		Pb ro conc	18.0	17.69	0.42	8.90	51.3	36.7	11.0
		Pb scav conc	8.3	24.31	0.74	17.30	32.5	29.5	9.9
Dow	5.0	Zn ro conc	17.0	1.94	0.14	54.31	5.3	11.6	63.7
E-2943-145-3		Zn scav conc	9.4	2.80	0.19	17.06	4.2	8.7	11.1
		Tailing	47.3	0.88	0.06	1.32	6.7	13.5	4.3
		Head (calc)	100.0	6.21	0.21	14.50	100.0	100.0	100.0
		Pb ro conc	34.7	14.53	0.48	15.35	89.2	70.8	35.5
		Pb scav conc	6.4	5.02	0.21	21.48	5.7	5.5	9.2
	10.0	Zn ro conc	14.3	0.79	0.17	48.83	2.0	10.2	46.1
		Zn scav conc	7.4	1.20	0.13	12.50	1.6	4.2	6.2
		Tailing	37.2	0.22	0.06	0.80	1.5	9.3	3.0
		Head (calc)	100.0	5.65	0.24	15.02	100.0	100.0	100.0

Surfactant 2% sol'n		Products	%	Assay %			% Distribution		
Type of reagent	L/t of ore		Wt	Pb	Cu	Zn	Pb	Cu	Zn
		Pb ro conc	8.5	28.28	0.75	8.78	41.2	25.1	5.1
		Pb scav conc	14.2	20.30	0.89	19.43	49.5	49.4	18.7
		Zn ro conc	18.1	0.98	0.13	53.68	3.0	9.4	65.7
	2.5	Zn scav conc	11.2	1.42	0.11	10.01	2.7	4.7	7.6
		Tailing	48.0	0.44	0.06	0.88	3.6	11.4	2.9
		Head (calc)	100.0	5.83	0.26	14.76	100.0	100.0	100.0
		Pb ro conc	16.2	19.24	0.53	9.95	50.6	36.4	10.7
		Pb scav conc	13.1	19.48	0.77	19.55	41.3	42.4	17.0
Dow	5.0	Zn ro conc	24.1	1.05	0.09	41.66	4.1	9.3	66.7
E-2943-145-4		Zn scav conc	8.4	1.52	0.09	6.85	2.0	3.4	3.8
		Tailing	38.2	0.32	0.05	0.72	2.0	8.5	1.8
		Head (calc)	100.0	6.17	0.24	15.06	100.0	100.0	100.0
		Pb ro conc	25.8	18.06	0.46	10.60	73.5	53.6	18.7
		Pb scav conc	8.5	14.93	0.55	23.14	20.0	21.2	13.5
	10.0	Zn ro conc	15.1	0.91	0.10	54.81	2.2	6.8	56.6
		Zn scav conc	7.3	1.37	0.17	15.84	1.6	5.4	7.9
		Tailing	43.3	0.41	0.07	1.12	2.7	13.0	3.3
		Head (calc)	100.0	6.34	0.22	14.62	100.0	100.0	100.0

POOR

QUALITY

ORIGINAL